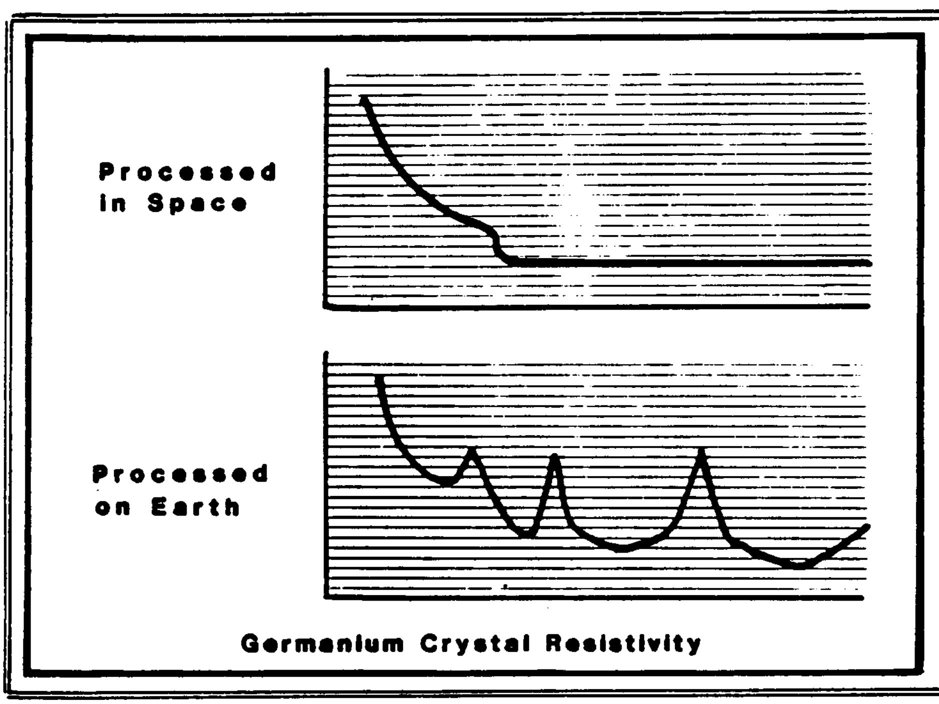
"USER REQUIREMENTS FOR THE COMMERCIALIZATION OF SPACE"

CONTRACT NASW-3674



TASK 5 - FINAL REPORT
DECEMBER 1984

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON , D.C. 20546

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SPACE STATION COMMERCIALIZATION

TASK 5 - FINAL REPORT

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I. FOREWORD

This report is written in fulfillment of Contract NASW-3674 (Task V) entitled "User Requirements for the Commercialization of Space." It was prepared by ECOsystems International, Inc. for the National Aeronautics and Space Administration Headquarters, Office of Commercial Programs, Technology Utilization Division.

This report follows a previous study depicting the details of MPS experiments performed prior to the shuttle era. It includes a discussion of the results of the pre-shuttle era and the currently completed shuttle experiments. These results are summarized in the Appendices of this report for the reader's convenience.

From these summaries of MPS research, the MPS component of a cost-effective earth-orbiting space station may be inferred on the basis of user requirements and plausible research and development.

The overall goal of this project is to stimulate interest within the non-aerospace industry to pursue scientific research and/or commercial operations in near-earth orbit. Two steps were taken to augment this goal:

- Assess the opportunities for materials processing made available through the Space Shuttle program.

- Synthesize the status, results and potential of the science of Materials Processing in Space (MPS) with a view to eventual use of commercial processes which would be significantly facilitated or improved in an earth-orbit space environment.

II. EXECUTIVE SUMMARY

2.0 Purpose

Since the early 1970's, the U.S., European, and Soviet Space Programs have explored the use of the space environment for the development of new and improved processes and materials. The results of this work, while still limited, has been encouraging.

As the costs of operating in space continue to fall, the development of materials with unique properties not achievable on Earth is approaching commercial practicability. The microgravity and vacuum of space are already proven arenas for experimentation into materials processes difficult or impossible to achieve on Earth. In the near future these can become an important complement to terrestrial industrial operations.

Potential users of microgravity and the Materials Processing in Space (MPS) programs need to be aware of the program findings, and prospects for the future, in order to assess their own opportunities for improved or new processes and products.

For example, the communications industry has opened up new commercial markets through the use and deployment of satellites. In 1985 the Space Shuttle is expected to perform commercial activities on the order of $650 million -- another indication of the growing commercialization of space.

2.1 Overview of MPS

Prior to the launching of Apollo flights, ground-based research set the stage for MPS. A preliminary series of space experiments were conducted during Apollo flights 14, 16 and 17. MPS studies have subsequently continued and expanded into broad potential commercial applications. The theoretical studies and experiments have covered wide areas of possible microgravity and vacuum applications. The reality of commercial manufacturing in space is close at hand, with the development and deployment of a Space Station, scheduled for the early 1990s. Figure 2-1 provides an overview of the evolution of MPS programs.

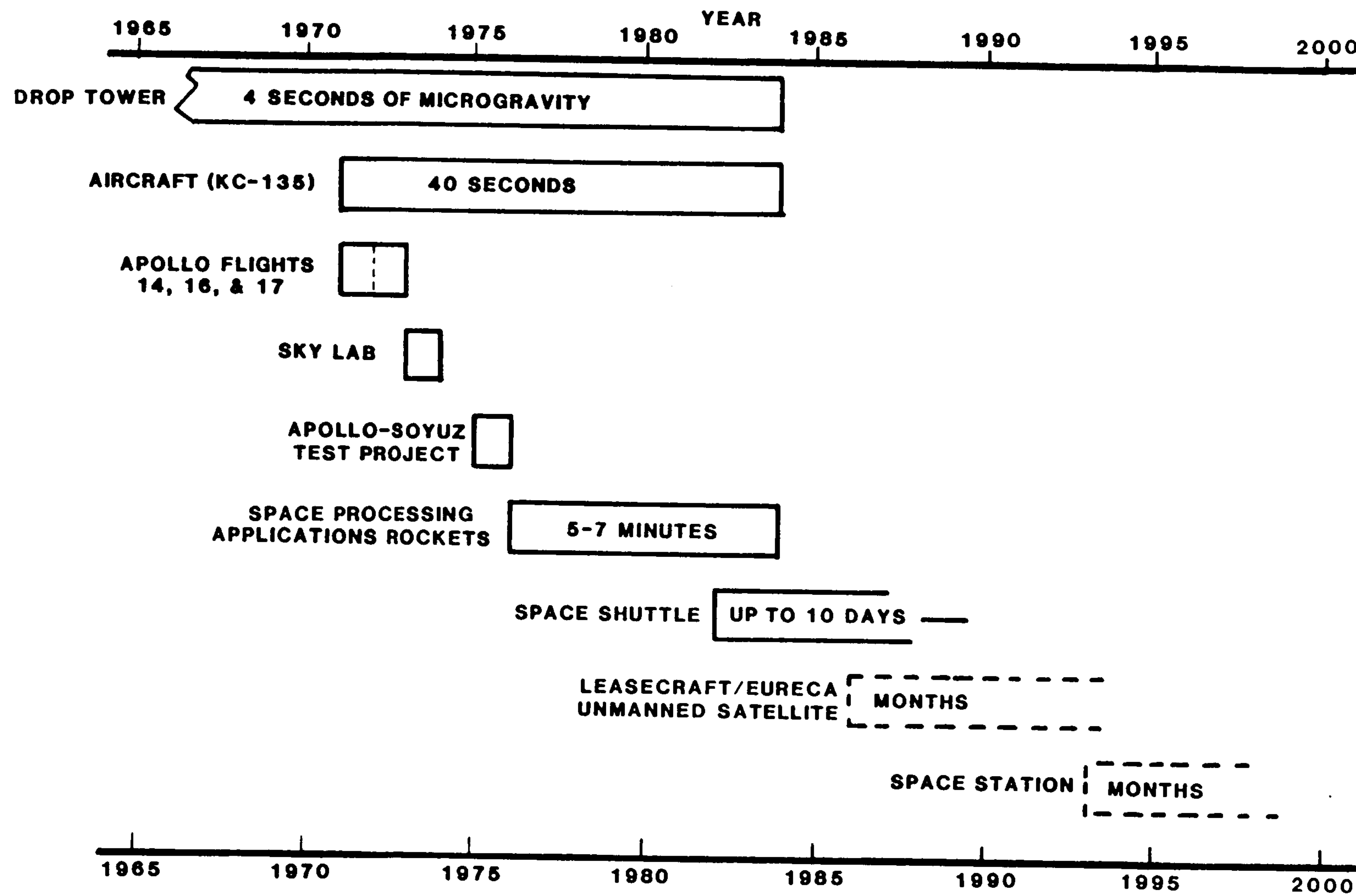


Figure 2-1. Evolution of MPS Programs

2.2 The Space Environment

The space environment for MPS operational applications is principally distinguished by its microgravity ("weightlessness") and vacuum components. Figure 2-2 shows the unique properties and potential applications of the space environment.

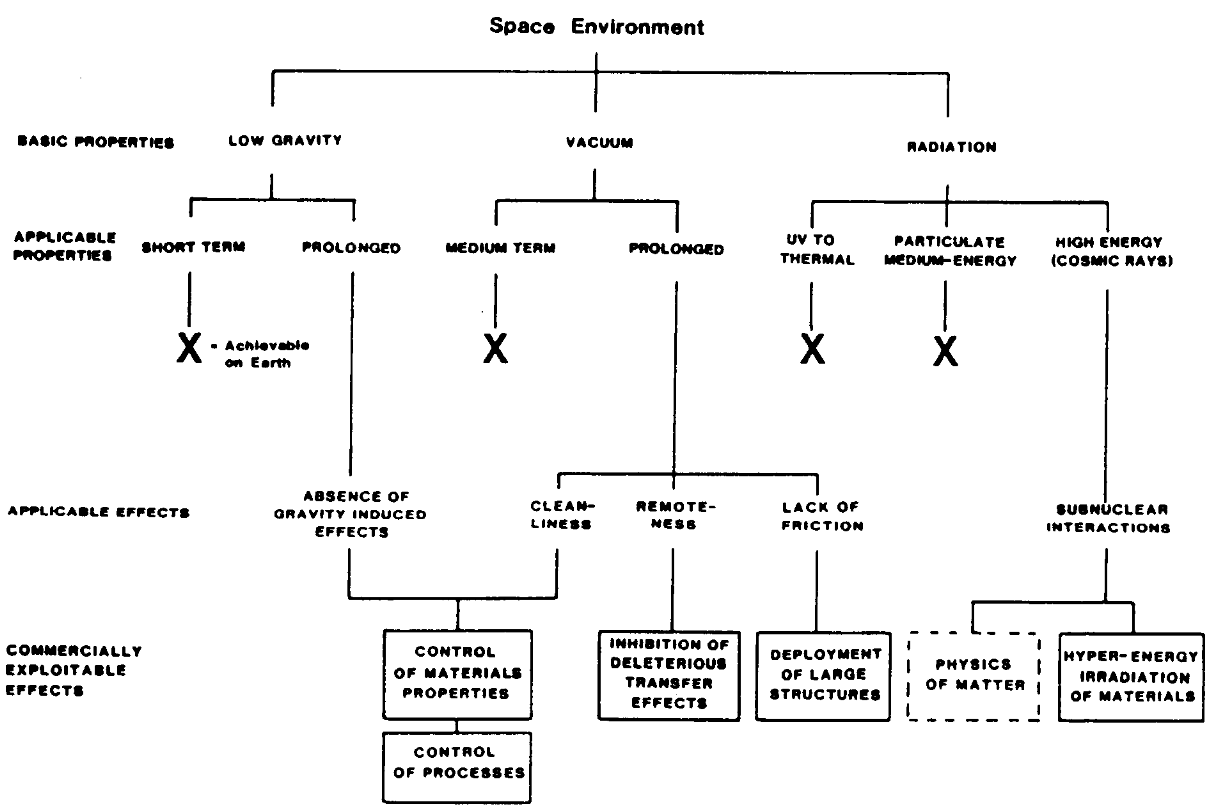


Figure 2-2 Unique Properties and Potential Application of the Space Environment

MICROGRAVITY - The term used to describe the minute gravitational force acting on an orbiting spacecraft is microgravity. In Earth orbit the gravitational force can be reduced to the realm of one millionth (10^{-6}) of the force at the Earth's surface.

Small spurious forces are created by orientation maneuvers and any movement within the spacecraft. These spurious forces cause small departures from ideal microgravity conditions.

In microgravity, the occurrences of important and unique phenomena have been demonstrated. For example, fluid deformation due to hydrostatic pressure does not occur, and convection currents due to warmer portions rising and cooler portions sinking are absent. The effects of buoyancy and sedimentation are eliminated; fluids do not separate due to density differences. This has led to significant processing discoveries.

VACUUM - The Earth orbital space medium is not a perfect vacuum. Matter, mostly a plasma, i.e., a gas of charged particles, is present in low densities. Dust, neutral hydrogen, and other chemical molecules are also present in lesser amounts. The actual level of vacuum existing at low orbital altitudes is not much higher than what is present in commonplace objects, such as lightbulbs or vacuum tubes (10^{-6} to 10^{-8} Torr).

In space, a high degree of cleanliness, isolation, and the absence of aerodynamic friction are the three principal exploitable effects of long duration vacuum conditions.

Figure 2-3 below compares the data points of microgravity and high vacuum availability levels obtainable on Earth with those in space.

ENVIRONMENTAL PROPERTY	BEST CURRENTLY ACHIEVABLE ON EARTH	ACHIEVABLE IN SPACE
LOW GRAVITY (FRACTION OF EARTH GRAVITY)	• 10^{-4} FOR 40 SECONDS • 10^{-5} FOR 5 SECONDS	• 10^{-4} FOR WEEKS • 10^{-5} FOR DAYS • 10^{-6} FOR HOURS
HIGH VACUUM (FRACTION OF EARTH SURFACE PRESSURE)	• 10^{-17} FOR HOURS • VOLUME 25 LITERS	• 10^{-18} FOR MONTHS • VOLUME UNLIMITED

Figure 2-3. Data Points at Microgravity and High Vacuum Availability

2.3 The Rationale for Materials Processing in Space (MPS)

THE CONCEPT - The key to materials technology is to control properties of materials to produce quality products.

Low gravity and vacuum, singly or in combination, provide the materials industry with two key opportunities:

- The investigation of the properties of materials under exceptional conditions, either difficult or impossible to achieve on Earth
- The formulation of materials having unique properties

Both of these opportunities can be exploited to:

- Better understand the mechanisms of materials formation and behavior for the purpose of developing new or improved processes usable on Earth
- Exploit space itself as a facility wherein to manufacture special products of high value per unit weight

Figure 2-4 below breaks down the principal MPS categorization by objectives. These are more fully explained in Chapters III, IX and XIII.

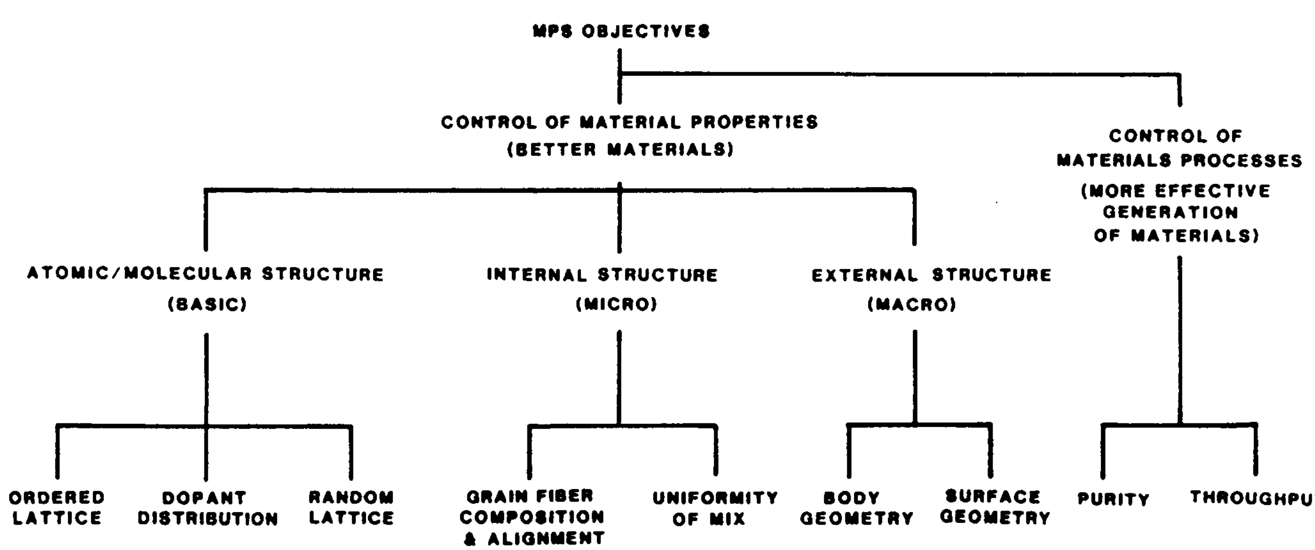


Figure 2-4 Materials Processing in Space Categorization by Objectives

2.4 Principal Industrial Applications of MPS

Industry's current interest in MPS centers on these major production techniques:

MATERIAL SEPARATION: The separation and purification of biological material through electrophoresis.

CRYSTAL GROWTH: The production of high purity crystals free from convection created imperfections.

COMPOSITE MATERIALS FORMATION: The production of mixtures of materials with different densities which would separate under normal gravity. In microgravity mixtures remain suspended during melting and solidification. This opens a new field of superconductors, eutectics, and higher strength alloys.

2.5 The Current Status of MPS

Less than 30 hours of MPS experimentation in microgravity have been conducted prior to the inauguration of Shuttle flights. The Shuttle is being used as a platform for confirming areas of promise, translating new processes and techniques into practice, and conducting longer term research into areas of interest.

Two specific Shuttle experiments are moving beyond basic research:

- Large monodisperse latex spheres production;
- The Continuous Flow Electrophoresis System (CFES) tests conducted by McDonnell Douglas/Johnson & Johnson.

Monodisperse latex spheres have been grown to the size of 18 microns with five times the uniformity of ground samples; spheres as large as 30 microns with less than 2% standard deviation from rounding have been produced as well. This MPS process is close to commercial scale-up.

The McDonnell Douglas/Johnson & Johnson CFES device has demonstrated a considerable improvement over conventional, ground-based devices — 500 times the throughput and five times the separation of living cells. Selected preparations of these cells are planned to be used in humans for therapeutic purposes. The actual biological materials to be evaluated and approved for clinical testing and marketing are proprietary under a joint endeavor agreement signed with NASA. The process of continuous flow electrophoresis is approaching the point where this clinical testing will be scaled-up to commercial levels.

2.6 Industrial Evaluation of MPS

Commercialization requires an orderly evolution from basic understanding to eventual industrial exploitation. This process begins with an understanding of the theory of the phenomena being exploited, followed by control of the process via the application of microgravity and/or vacuum. These typical steps in implementation of MPS are depicted in Figure 2-5. Finally these new processes are adapted to produce industrial quantities for use in the market place.

In the last five years an increasing number of industries have recognized the possible advantages of utilizing MPS.

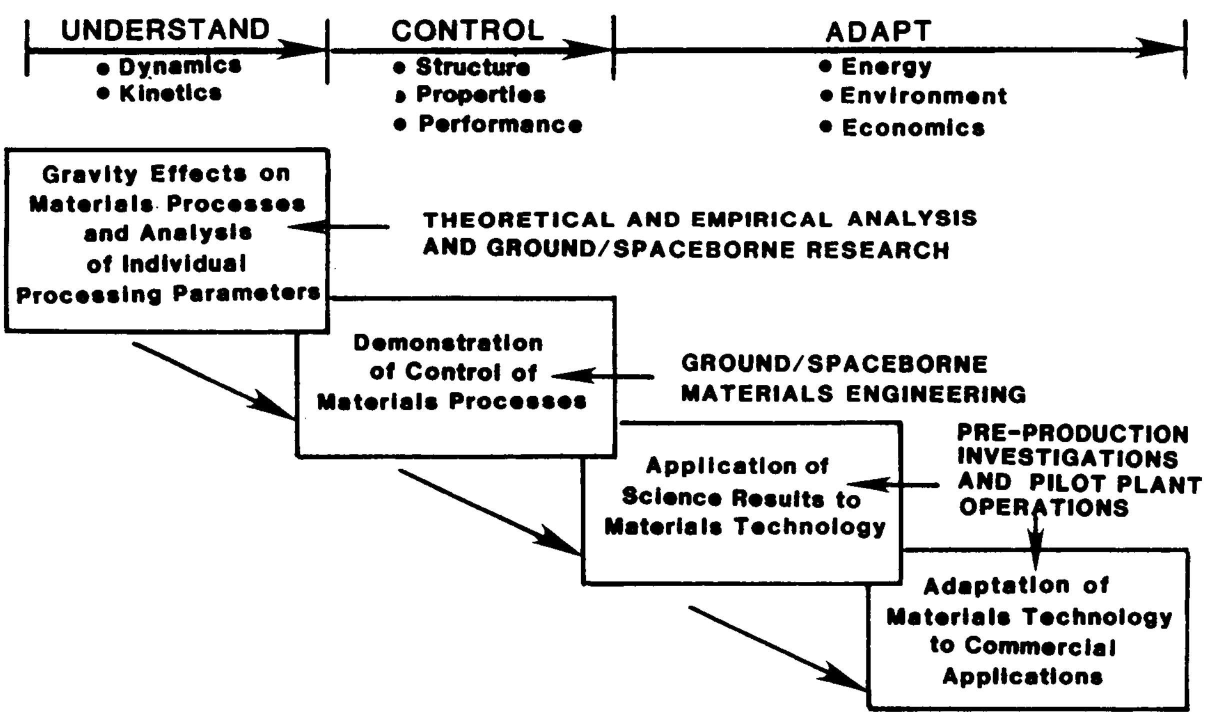


Figure 2-5. Typical Steps in Implementation of MPS

2.7 Industrial Relations With NASA

NASA is required, by Congressional mandate, to transfer its available technology, when possible, to industry.

The terms of these NASA/Industry interactions are highly flexible and can be individually tailored to the needs of each interested industry. Figure 2-6 provides an overview of the possible working relationships with NASA. Their structure is based on three types of arrangements:

- Technical Exchange Agreements, which allow industries to cooperate with NASA in ground-based research and analyses, and to have access to NASA's results, facilities, and personnel -- as long as the information is non-proprietary.

- Agreements sponsored by an Industrial Guest Investigator, who appoints a technical expert to collaborate with NASA experts on flight experiments.

- Joint Endeavor Agreements, by which industry and NASA share the effort and costs of a complete program, from feasibility study through flight tests to demonstration.

Negotiated terms include:

- Protection of proprietary industrial information;

- Industry rights to patents;

- Provisions for exclusivity;

- Others, negotiated case by case.

Type of Agreement	INDUSTRIAL GUEST INVESTIGATOR (IGI)	JOINT ENDEAVOR AGREEMENT (JEA)	TECHNICAL EXCHANGE AGREEMENT (TEA)
Primary Responsibility	GOVERNMENT (NASA)	SHARED	INDUSTRY
Industrial Responsibility	• Provide Scientist (Investigator) at no cost to the government • Contribution is negotiable	• Develop and fund experiment hardware costs	• Exchange of technical data • Funding of Company participation including development of experiment hardware • Shuttle flight and use of NASA facility costs
NASA Responsibility	• Manage the Overall Coordination of the program including Flight costs	• Share Shuttle flight and use of NASA facility costs • Refrain from entering into similar JEA competitive to the project	• Provide direct access to and results from NASA facilities and research • Assist in scheduling Shuttle/Spacelab flights
Who Owns Rights To Data/Inventions	GOVERNMENT (NASA) PUBLIC DOMAIN	NEGOTIABLE	INDUSTRY

Figure 2-6. Possible Working Relationships with NASA

NASA advisory services are available to industries interested in structuring cost effective programs of investigation, experimentation and testing. The course of its communications with NASA, industry's most frequent questions relating to MPS are:

- o What products have been produced?
- o How are proprietary data, patent rights and other protection provided?
- o What are available flight opportunities?
- o What supporting information (power-volume-thermal-data collection etc.) can be provided?
- o How much will flights cost?

The answers to these questions are subjects to be discussed with NASA's Office of Commercial Programs which can lead to an agreement between NASA and the potential user. The key ingredients of an agreement are:

- o a sound technical idea;
- o reasonable management plan;
- o a schedule of activities.

2.8 MPS Experiment Results

All MPS experiments conducted prior to Space Shuttle flights are summarized in Appendix A. Those experiments conducted on Shuttle flights are summarized in Appendix B.

The MPS investigations in Appendix A are subdivided into four categories:

1) Demonstrations of processes. These are tests, or series of tests, aimed at demonstrating processes during space flight. For example, the series of

electrophoresis processing tests performed on Skylab;

2) Experimental data points collected in a terrestrial low-gravity, or vacuum facility. In this category fall experiments aimed at demonstrating specific effects of the space environment, postulated by theory; for example, tests to validate the fact that convection does not operate under low-gravity conditions;

3) Theoretical analyses — for example, the expected MPS findings performed by the Bureau of Standards under contract to NASA;

4) Process technology or equipment developments necessary to enable precise measurements or collection of data unique to the space environment. These include special studies and techniques for the transfer of processes to Earth-based systems;

The MPS investigations in Appendix B are listed in conjunction with the nine completed STS flights, and subdivided into the four categories defined in 2.8.

III. BACKGROUND AND OBJECTIVES

3.0 Background

Since the inception of its activities, NASA, in the interest of industrial development and varied public service, has pioneered the use of the unique physical properties of space. This exploratory venture has given rise to well-known technological products and services -- communication satellites, atmospheric and earth observation space systems, and the growing industry of privately-owned space launchers and service satellites.

Throughout the last decade, NASA has intensified its investigation of the exploitation of certain properties of the space environment -- primarily low gravity and high vacuum -- to improve industrial processes. NASA performed approximately 130 theoretical and experimental investigations in the microgravity sciences prior to the inauguration of the Space Shuttle program, either in ground produced microgravity conditions or in conjunction with actual space flights. Ground-based microgravity conditions were created through the use of drop facilities, aircraft in parabolic trajectories, or coasting rockets. Space-based microgravity conditions were realized on Apollo, Skylab, Apollo-Soyuz Test Project (ASTP) and, most recently, Space Shuttle flights including Spacelab. Finally, NASA's newest planned endeavor, the earth-orbiting Space Station, will serve as a full-fledged development and prototype production facility.

3.1 Objective

The principal objectives of this investigation into MPS are threefold: 1) to provide industry with the latest results of microgravity materials processing, 2) to indicate areas of promise for further MPS experiments, and 3) to indicate potential areas in which this research can be used commercially. This report on the available research results will facilitate the compilation of all completed and planned experiments in MPS.

IV. DATA SOURCES

The majority of the MPS data used in this study was collected from six major sources of pre-Shuttle and Shuttle experiments:

- o NASA Technical Memoranda (TM)
- o Principal Investigator (PI) and Contractor Reports
- o Proceedings of Conferences
- o Journal Articles
- o Articles derived from Bibliographies of MPS literature
- o Spacelab Investigator's Presentations

Table 4-1 illustrates specific examples of data sources available for this information.

NASA TMs, provided ground-based research as well as research from the space missions of Apollo, Skylab, and the Apollo-Soyuz Test Project. Experiment objectives, discussions and some results are included in these documents.

These TMs, however, frequently lacked a discussion of experiment results. Letters were sent to 65 Principal Investigators (PIs), requesting the results from their most recent experiments. Six of the PIs responded with new information; ten had changed jobs without leaving a forwarding address; nine sent copies of old information on file; and three contributed a wealth of updated, usable results which were incorporated into the MPS results table. Morever, phone calls were made to approximately 35 NASA personnel involved in areas of materials processing.

TABLE 4-1

EXAMPLES OF DATA SOURCES

I. NASA Technical Memoranda

- Naumann, R.J., 1979. Early Space Experiments in Materials Processing. NASA TM-78234
- Pentecost, E., 1982. Materials Processing in Space. Program Tasks. NASA TM-82496

II. Principal Investigator and Contractor Reports

- Gelles, S.H.,E.W. Collings, W.H. Abbott, and R.E. Maringer, 1977. Analytical Study of Space Processing of Immiscible Materials for Super-Conductors and Electrical Contracts. NASA CR-150156.

III. Proceedings of Conferences

- Marshall Space Flight Center, NASA, 1974. Proceedings of the Third Space Processing Symposium -- Skylab Results (2 Volumes).

IV. Journal Articles

- Covault. C., 1982. Payload Tied to Commercial Drug Goal. Aviation Week and Space Technology, May 31, Issue.

V. NASA Bibliographies of MPS Literature

- Pentecost, E., 1982. Materials Processing in Space Bibliography. NASA TM-82466.

VI. DFVLR Abstracts, Etc.

Journal articles provided summaries of specific experiments. Proceedings from conferences also provided excellent discussions and some results of successful and potentially successful experiments. Preliminary presentation materials on experiments pertained in shuttle Middeck and Spacelab has provided a significant wealth of new information.

A sizable collection of other literature sources, was used as well, dealing with microgravity included press kits (STS-3 through 9), European Space Agency (ESA) brochures, and Space Transportation System User handbooks, statistical information was retrieved from Federal agencies, including the Department of Commerce, the National Science Foundation, the General Accounting Office, and the Senate and House testimonies on NASA appropriations. Catalogs of product lines and price lists were obtained from a variety of U.S. pharmaceutic and chemical manufacturers, which provided a data base of product prices.

V. MARKETING MPS

5.0 Background

In essence, commercialization of space requires the application of the most cost-effective technology possible to induce a suitable segment of the industrial community to use the space environment for profitable purposes. Two interrelated marketing techniques facilitate this goal:

- Identification of a market

- Capturing of a market

5.1 Identification of a Market

A potential market, in industrial terminology, is categorized as "gross", "addressible" or "capturable".

Gross market designates the total population of possible customers for a given product or service. The gross market for MPS, for example, would include all of those industries which produce materials, and/or process materials into added-value products.

The addressable market, a sub-class of the gross market, consists of those potential customers whose requirements for products and/or services relate closely to the products and/or services being offered by the "selling" industry. In the case of MPS, the addressable market includes industries which either:

- Produce products of high specific value, i.e., high cost per unit weight; or

- Engage in "exotic" processes whose intimate workings are not fully understood, and therefore could benefit from additional insight through R&D efforts. In order for a process or product to be applicable to this market, its potential benefit must be convertible into potential sales from either the improved understanding of a product or process, or the more efficient performance of a process.

The capturable market is that segment of the addressable market which will actually purchase the products or services being offered. In the case of MPS, the capturable market represents those customers who can be expected to eventually benefit from MPS activities.

Addressable and capturable markets are statistical rather than deterministic concepts. They become deterministic after the sales are actually completed.

5.2 Capturing of a Market

Existing approaches to capturing a suitable share of the addressable market are variants or combinations of two principle methods:

- o The canvass method, and
- o The applications development method.

Through the canvass method the seller seeks to elicit customers from within the base of the addressable market by offering a product or service on a statistical basis. The seller assumes that a certain percentage of prospective customers will be converted to "captured" customers. The underlying assumption in the canvass approach is that the higher the total number of prospective customers contacted, the higher the actual number of customers there will be.

By using the applications development method, the seller assesses the prospective customer's business; and then markets his product or service in such a way as to provide specific economic advantages to the prospective customer. In other words, the seller markets a "result" demonstrably benefitting the buyer, i.e., predicated upon the buyer's capacity to use a particular product or service.

The main criterion for choosing one of these marketing methods is cost/effectiveness, i.e., the ratio of sales to the cost of the resources expended to produce the sales.

The canvass method has proven to be most cost/effective in cases where the application of the product or service is obvious or readily conceived by the prospective customer. This is the case, for example, of consumer products.

The applications development method has demonstrated maximum cost/effectiveness in cases where the product or service offered is not obviously related to the prospective purchaser's advantage. This is generally true of complex, high technology processes. A typical example is offered by the introduction of computers during the fifties. The potential buyers had difficulty in associating the use of computers with their business needs. Successful computer manufacturers approached this marketing problem by initially analyzing their prospects' operations. They then configured and presented their product in terms of a service which would increase the industrial productivity of a targeted customer's operation.

The applications development method has been recommended in a previous study. While the canvass approach has been and is still being employed by NASA in other space industrialization efforts, the applications development approach should reach and effectively influence a wider base of interested industries.

The applications development method can be adapted to MPS through the following procedure:

- Characterize the space environment and identify its unique properties;
- Isolate the exploitable effects of the space environment in general, and define, qualify, and quantify those characteristics specifically applicable to MPS techniques;
- Derive and categorize the proven applications of these effects, i.e., the results achieved thus far in NASA's MPS effort;
- Summarize the most promising payoffs anticipated from MPS, based upon the expected experimental and/or theoretical results to be achieved;

- Identify corresponding candidate commercial products and processes which could be improved and enhanced through MPS;

- Identify specific industries as candidates for manufacturing these products or using these processes;

- Initiate a program of direct queries of these industries to assess their interest in and their reservations and potential difficulties with the use of the space environment for profitable ventures; and

- Develope a modus operandi by which NASA can interface with the candidate industries.

VI. SPACE ENVIRONMENT PROPERTIES

6.0 General

In this chapter the exploitable environmental properties of the space environment are examined from a "Top-Down" view. The principal effects of the space environment are discussed first; the applicable properties and effects are then identified, quantified and compared to those occurring at the Earth's surface; finally, the current status of scientific or commercial exploitation of these effects is explored.

The "Top-Down" view of unique properties and potential applications of the space environment, shown in Figure 2-2 and repeated in Figure 6-1, is explained in the subsections which follow.

6.1 Isolation of the Principal Effects of the Space Environment

The environment for MPS operations is characterized by: (1) low gravity; (2) the rarefaction of the medium (vacuum); (3) background radiation; and (4) synoptic overview of the Earth's surface and atmosphere.

The latter effect, i.e., synoptic overview, has given rise to the important disciplines of communications and remote sensing from space. These are the first space based operations to transcend the barrier of research and be successfully commercialized. However, the synoptic overview does not effect materials processing and therefore will not be considered further.

6.2 Microgravity

In Earth orbit the gravitational force can be reduced to the realm of one millionth (10^{-6}) of the force at the Earth's surface. The spacecraft is actually in a state of freefall but its orbital velocity and direction carry the vehicle beyond the Earth. In this situation the centrifugal force acting upon a spacecraft equals the centripetal pull of gravity: although gravity is active in Earth orbit, the effect is essentially balanced by the centrifugal force of the vehicle's orbital motion.

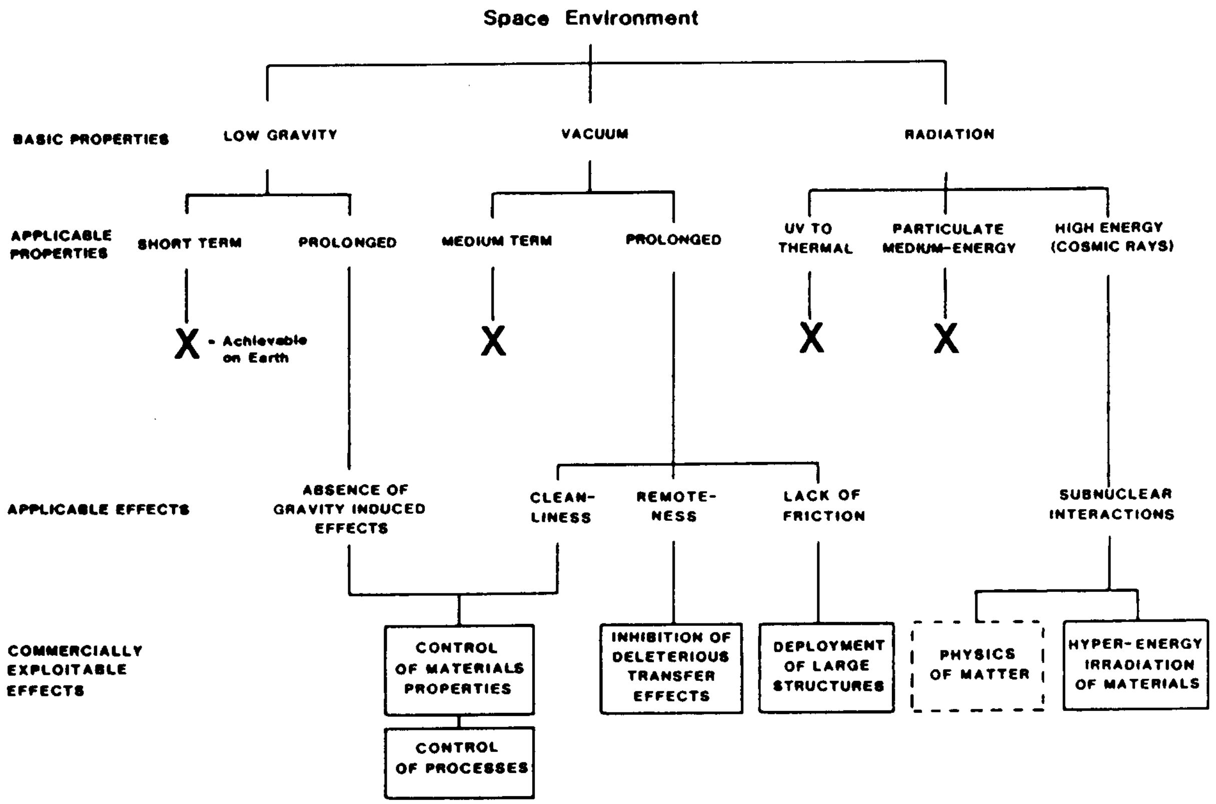


Figure 6-1. Unique Properties and Potential Application of the Space Environment

In space, a slight aerodynamic drag causes deceleration, producing a condition referred to as "weightlessness" or, more accurately, microgravity. In this microgravity condition, the gravitational force is smallest at a spacecraft's center of mass and changes slightly as one moves away.

Besides these slight gravitational forces, other acceleration factors effect an orbitting spacecraft. Orientation maneuvers and movements within a spacecraft create small, spurious forces; centrifugal forces are created from spacecraft altitude motion during the course of material science experimentation. These forces, causing small departures from ideal microgravity conditions, are known as "g-jitter". Table 6-I illustrates the principal residual g-levels, present within spacecraft in low earth orbit, induced by phenomena within the environment of the spacecraft.

TABLE 6-1

PRINCIPAL RESIDUAL G-LEVELS PRESENT WITHIN SPACECRAFT IN LOW EARTH ORBIT (400 KM)

APPROXIMATE FORCES INDUCED BY:	EFFECT, KILOGALS
CONTINUOUS BELLY-DOWN ORIENTATION	$1.33 \times 10^{-7} \times d$
CONTINUOUS INERTIAL ORIENTATION	$3 \times 10^{-7} \times d \sin 2 \frac{t}{T}$
ATMOSPHERIC DRAG	$10^{-3} \frac{A}{W}$
Example: for $A = 100\ m^2$, $W = 100$ tons, $G \approx 10^{-6}$ Kilogals	

d = distance from C.G., meters

T = orbital period, minutes

t = time elapsed, minutes

A = spacecraft frontal area, m^2

W = spacecraft weight, Kg

1 Kilogal $\cong$ 1 g

In microgravity, important, unique activity of phenomena have been discovered. For example, fluid deformation from hydrostatic pressure does not occur; convection currents, from the rising of warmer and the sinking of cooler portions, are absent; and the effects of buoyancy and sedimentation are eliminated, and thus, fluids do not separate from density differences.

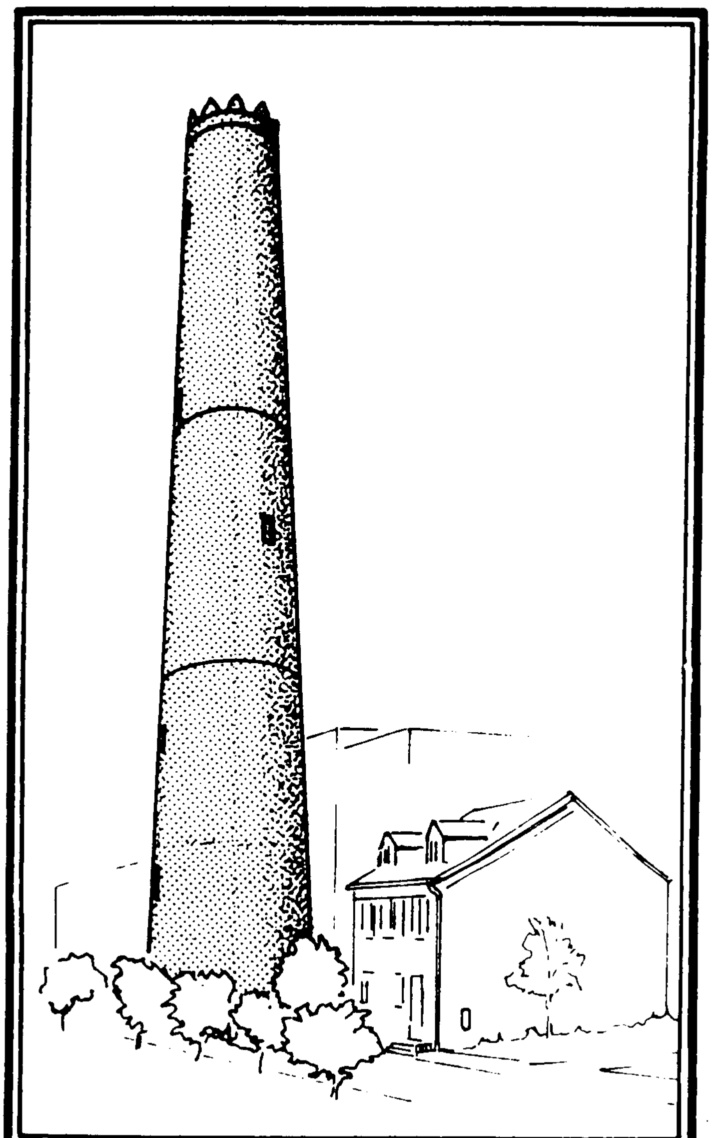
Low levels of gravity are achievable on Earth for short time intervals. The oldest such method is the release of objects from tall structures, a method first utilized by Galileo by dropping objects from the Leaning Tower of Pisa. During the eighteenth and nineteenth century, "shot towers" were used to cast round pellets by dropping molten lead through a sieve into an underlying tub of water, see Figure 6-2.

There are some limitations, however, to these Earth-based methods. Drag effects of a free-falling objects in the atmosphere counter the gravitational-acceleration force. Drag and velocity will increase with fall time until a point is reached when the drag force is equal to the object's weight. At this point the low-g effect will be rectified.

This problem of atmospheric drag can be eliminated through the use of evacuated drop tubes. However, the cost of these structures and the technology required to create high vacuum for large volumes and long durations has thus far limited their height and therefore the time of microgravity simulation. The tallest evacuated tower in existence is at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Its 100 meters allow free-fall durations of 4.2 seconds.

Another method employed to minimize atmospheric drag is the use of an aerodynamic shield, such as the 130 meter drop facility at the Lewis Research Center. Other earth-bound methods of producing low-g for short periods of time are parabolic trajectories of aircraft and coasting rockets.

The Micro-g simulation on Earth is shown in Figure 6-1, in which the branch of the top-down view connoting "short-term low-gravity" is terminated at the second level of the top-down chart.



BALTIMORE SHOT TOWER

A low gravity production facility built in 1829 and used during the Civil War and up to World War II to produce round shot by dropping molten lead 230 feet onto a vat of water. The molten lead solidified in free fall yielding spherical pellets of the desired caliber.

Figure 6-2. The Baltimore Shot Tower

6.3 The Rarefield Medium

The Earth orbital space medium, often designated as a void or vacuum, is not entirely empty. Matter, mostly a plasma, i.e., a gas of charged particles, is present in low densities. Dust, neutral hydrogen, and other chemical molecules are also present in lesser amounts.

Characteristics of the average values of available vacuum in Earth orbit are summarized in Figure 6-3. It is apparent that the level of vacuum available at low orbital altitudes is not much higher than what is present in commonplace objects, such as lightbulbs or vacuum tubes (10^{-6} to 10^{-8} Torr).

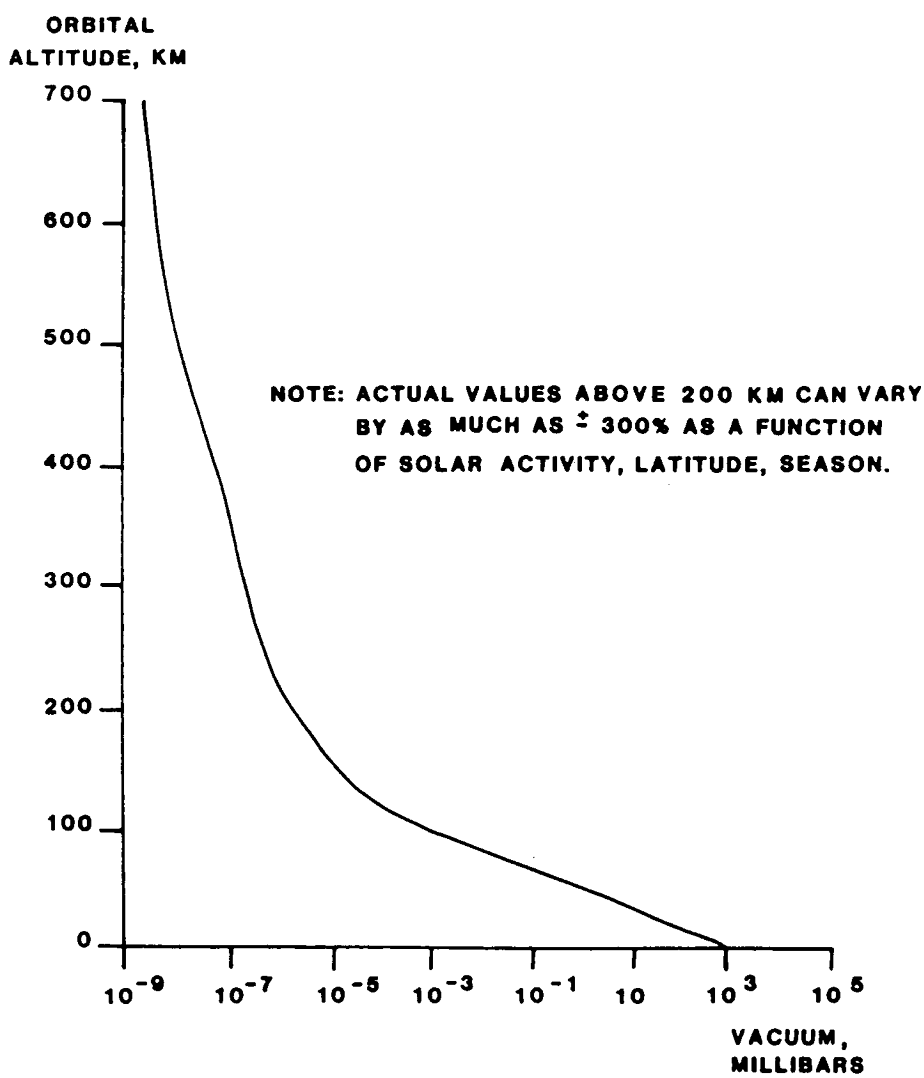


Figure 6-3. Average Values of Vacuum Available in Earth Orbit.

A significant improvement in this vacuum level can be attained in the wake of a "shield" moving at orbital velocities. The vacuum effect behind a moving shield acts as a "sweeper" of the residual particles, as shown in Figure 6-4. The theoretical values of vacuum, in proximity of such a shield, reach upwards of 10^{-17} Torr. Higher levels of vacuum in Earth-based vacuum chambers are achievable for limited time spans ranging from hours to days. These limited time spans and Torr, however, inhibit the effectiveness of Earth-bound experimentation and commercial exploitation. Thus, in Figure 6-1, the corresponding branch of the top-down view is terminated.

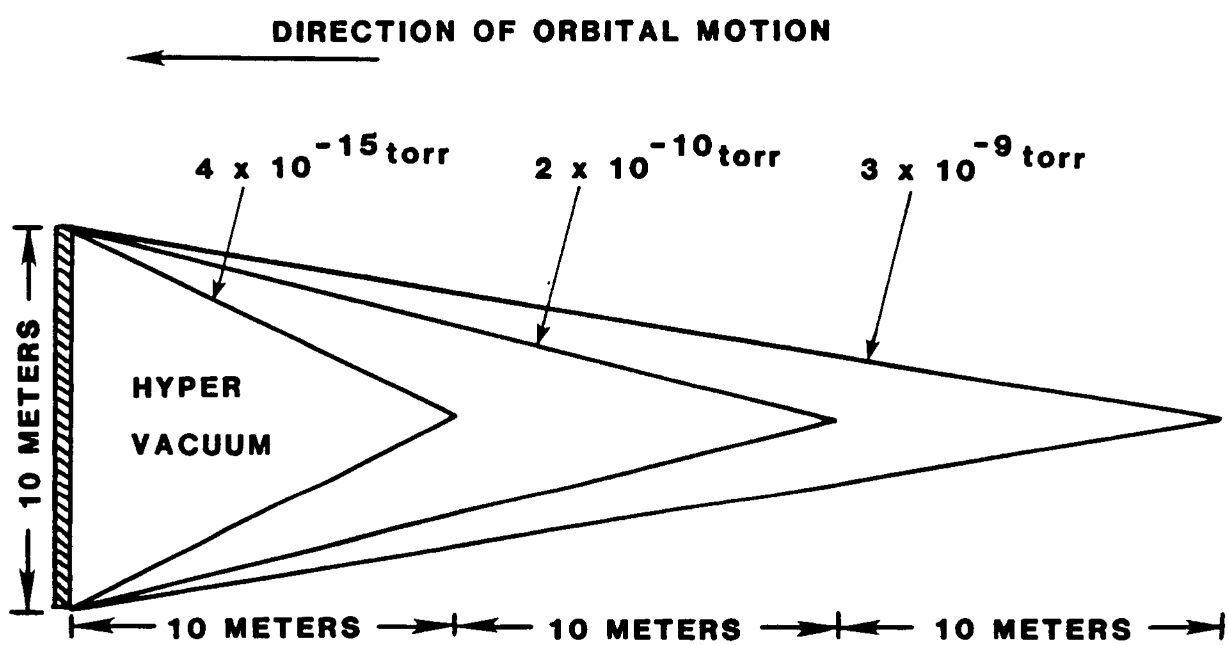


Figure 6-4. Vacuum Effect Behind a Moving Shield (Adapted from Naumann, Materials Processing in Space, Nasa SP-443.)

The long duration vacuum condition in space produces three principal exploitable effects, see Figure 6-1.

1. High degree of cleaniness or purity:

   o This characteristic is apparent in materials processing in long duration vacuum due to the tendency of unwanted materials to evaporate.

2. Isolation:

   o The continuous high vacuum of space acts as an "isolator", preventing deleterious substances from spilling over into the Earth environment. This exploitable effect relates especially to the control of disease-causing or toxic substances, such as pathogens or nuclear debris.

   With respect to nuclear debris, while it is not neutralized by vacuum per se, its attendant energy attenuates, in accordance with the inverse square law, by virtue of the distance between orbital altitudes and the Earth's surface. It is reduced further by the absorbing effect of the atmosphere. Because of this isolating capability of space, the removal of nuclear debris, from the Earth's surface to space, has been advocated in the past; however, it has not been attempted because of launch failure and the international treaties prohibiting this usage of the space environment.

3. The absence of aerodynamic friction:

   o This effect permits the deployment and maintenance of large structures, such as an antenna for communications purposes.

6.4 Radiation

Space is permeated by a wide spectrum of electromagnetic and particulate radiation. In Figure 6-5 the spectral irradiance of sunlight is compared with the solar exo-atmospheric spectrum.

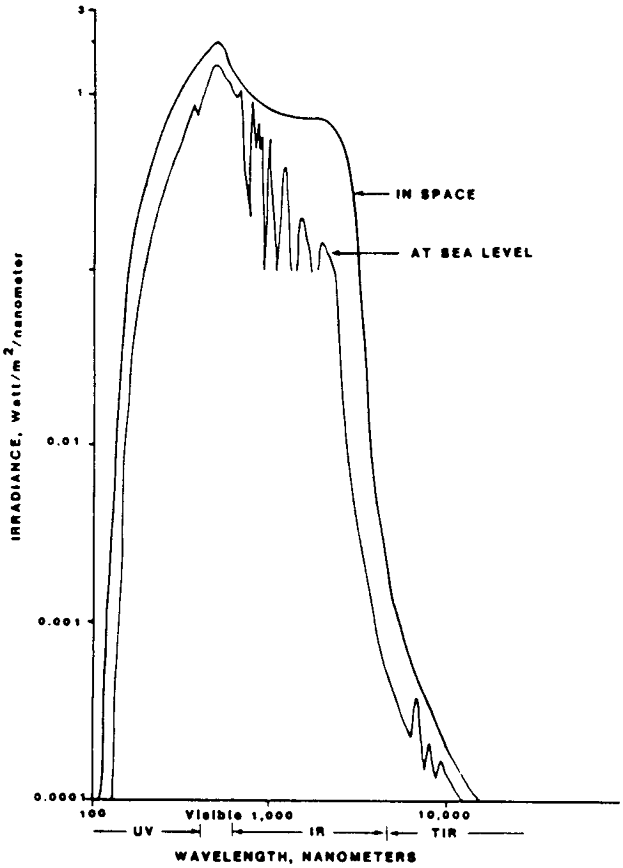


Figure 6-5. Spectral Irradiance of Sunlight

Note that the ultraviolet, x-ray, and thermal infrared portions of the spectrum are effectively filtered by the Earth's atmosphere. However, those portions of the electromagnetic solar spectrum, which are absent at the Earth's surface, can be simulated on the ground. Thus, the corresponding branch of the top-down tree is terminated in Figure 6-1.

The two principal sources of particulate radiation are the solar wind plasma and cosmic rays.

The solar wind is composed primarily of protons and electrons with ion traces of helium, oxygen, carbon and other elements. The kinetic energies of the particles composing the solar wind are relatively modest, well within the realm of what can be reproduced on Earth. Consequently, the corresponding branch of the top-down tree of Figure 6-1 is terminated.

Cosmic rays, which originate in galactic space, consist of particles (protons and nucleons) possessing energies ranging upwards of 10^8 billion electron volts (Bev). These high-energy particles do not reach the Earth's surface because they "split" and "degenerate" upon colliding with atmospheric molecules. Such high energies, at the present time, cannot be generated even in the best available ground-based particle accelerators. The most energetic of these accelerators is capable of 600 Bev, or several orders of magnitude less than natural cosmic rays.

A potential application of these energetic particles is the irradiation of materials. Irradiation is currently being performed industrially in such applications as used in the conditioning of elastometers, the preservation of foodstuffs and in hi-energy research. The space environment offers the opportunity of testing these irradition effects of a long duration use of hyper-energy particles.

6.5 Commercial Application of Space

The current status of research and development into the commercially exploitable effects of the space environment is shown in Table 6-2. Further MPS research in long duration microgravity, lift vacuum and high energy, should concentrate on those commercially applicable effects which are not readily or cost-effectively created on Earth.

The commercial application of the space environment is currently being researched by NASA, The European Space Agency, the U.S.S.R. and Japan.

TABLE 6-2

STATUS OF DEVELOPMENT OF COMMERCIALLY EXPLOITABLE EFFECTS OF THE SPACE ENVIRONMENT

APPLICATION	STATUS
• HYPER-ENERGY IRRADIATION OF MATERIALS	• UNEXPLORED
• BASIC PHYSICS OF MATTER	• INVESTIGATED IN SOVIET "PROTON" SATELLITE • RESULTS: LIMITED VALUE DUE TO LOW DENSITY OF COSMIC RAYS
• INHIBITION OF DELETERIOUS TRANSFER EFFECTS	• NUCLEAR WASTE DISPOSAL INVESTIGATED • REJECTED DUE TO HIGH COST AND RISK OF CONTAMINATION FROM LAUNCH ABORTS
• DEPLOYMENT OF LARGE ANTENNA STRUCTURES	• APPROXIMATELY 15 ENGINEERING STUDIES PERFORMED • MARKET ANALYSIS NOT YET PERFORMED • POTENTIAL HIGH COMMERCIAL VALUE TO COMMUNICATION INDUSTRY
• CONTROL OF MATERIALS PROPERTIES AND CONTROL OF MATERIALS PROCESSES	• SUBJECT OF ONGOING MPS PROGRAMS IN U.S., U.S.S.R., EUROPE, JAPAN

VII. MPS PROCESSING TECHNIQUES

7.0 Purpose

The purpose of this Chapter is to examine the following processing techniques which have attracted the most attention in MPS research:

- o Particle Separation and Purification
- o Crystal Growth
- o Containerless Processing
- o Composite Casting
- o The processing of Monodisperse Latex Spheres

7.1 Particle Separation and Purification

Biological materials can be separated and purified in a fluid by the application of an electric charge. In this process, known as Electrophoresis (Figure 7-1), biological material is introduced into a carrier fluid (buffer solution). Ions within the solution combine with molecules of the biological material to form charged particles. When an electric field is applied, the particles begin to flow through the carrier fluid at a velocity directly proportional to their charge. Terminal velocity will be reached when the viscous drag force equals charge drive force. In time the particles will separate into highly concentrated and uniform clusters of biological particles which can be collected for scientific or medical use.

Improved separation and purification techniques are frequently needed in biomedical research where cell components, cell byproducts and proteins are typically found in very low concentrations, or embedded in matrices of other very similar materials, e.g., beta cells in a mixture of cells comprising a pancreas. Purification is also required if a material contains substances which are potentially harmful or produce undesired side-effects.

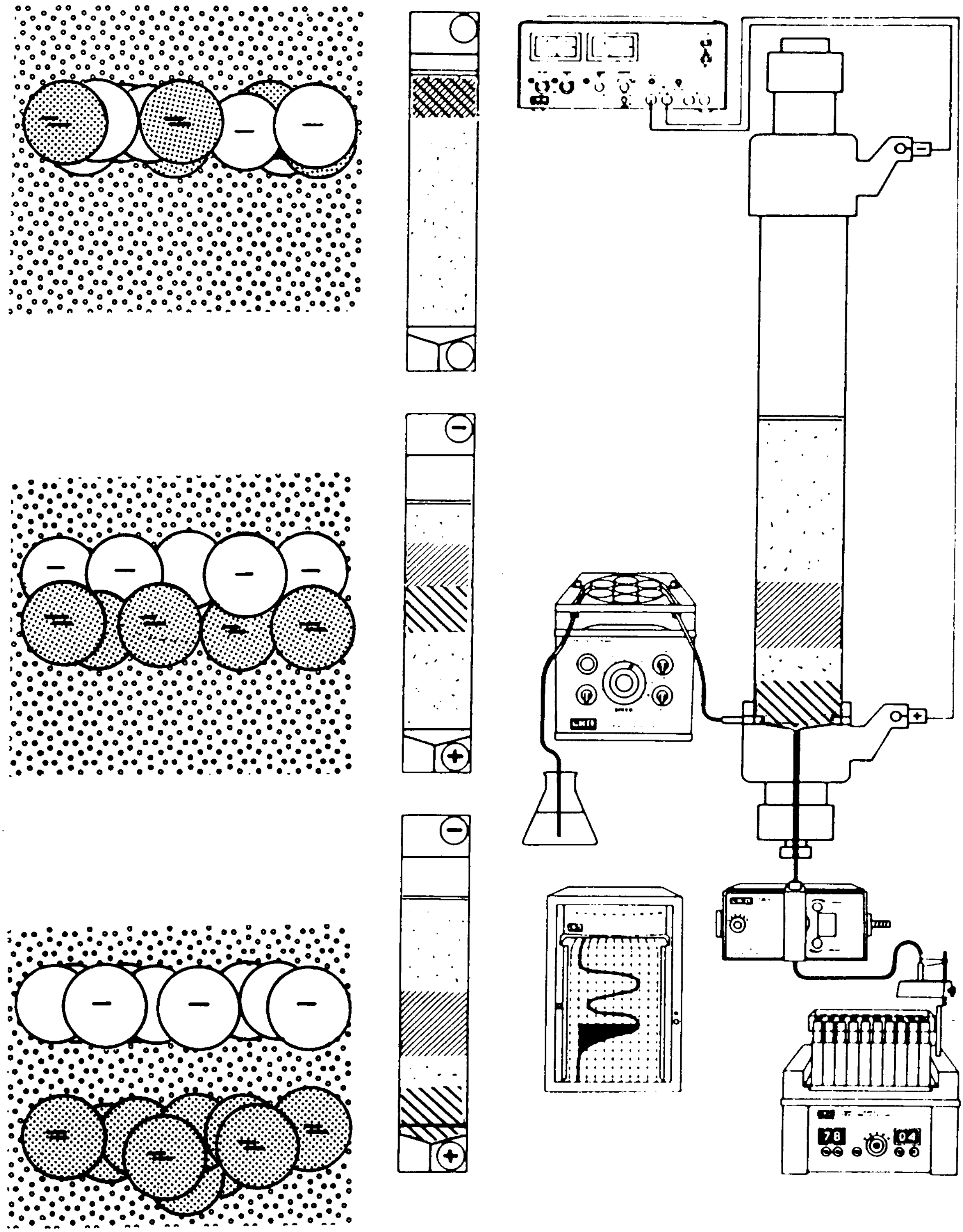


Figure 7-1. Electrophoresis

Adapted from "Materials Processing in
Space Early Experiments" pg. 30 Fig. 2.19

Electrophoresis is significantly limited on Earth, however, by convection currents which tend to stir up the fluid, and by problems of sedimentation and buoyancy. On Earth the density of a carrier fluid begins much lower than the density of most proteins, which causes the target materials to settle. This Earth-bound concentration ratio of biological material to carrier fluid is limited to about 0.02 percent.

In microgravity, operations of space concentration levels of biological material can be increased to 25 percent (125 fold), in the absence of sedimentation and convection. Moreover, sample inlet ports can be increased and applied voltage can be accelerated in space. As a result, a 500 times increase in throughput and a four to five times increase in purity are possible in space based electrophoresis. The associated problem of maintaining active, separated cells during their return to Earth is currently being researched.

The electrophoresis technique known as isoelectric focusing makes use of particle motion created when the ph of a particle differs from the ph of the surrounding medium. In this process, diagrammed in Figure 7-2, a buffer solution creates a ph gradient when an electric charge is applied. Sample material, injected at the low ph end, flows toward the higher ph, and then separates as the particle ph mathes the buffer ph. At this point, called the isoelectric point, particle motion will cease, and particles from the sample material with similar ph values will collect. Isoelectric focusing, however, does not work on living tissue.

The most promising electrophoresis technique, continuous flow electrophoresis, involves a continuous flow of both carrier fluid and biological material, see Figure 7-3. An electric charge is applied perpendicular to fluid flow, causing the target material to delect across the field of flow. The fluid and separated biological material are then collected in a series of tubes spread across the exit ports.

McDonnell-Douglas Corporation and Ortho pharmaceuticals, a division of Johnson & Johnson, have manufactured a Continuous Flow Electrophoresis System (CFES), Figure 7-3, which was flown on six STS flights, see Appendix B. These experiments with CFES have encouraged the development of hardware capable of commercial levels of production.

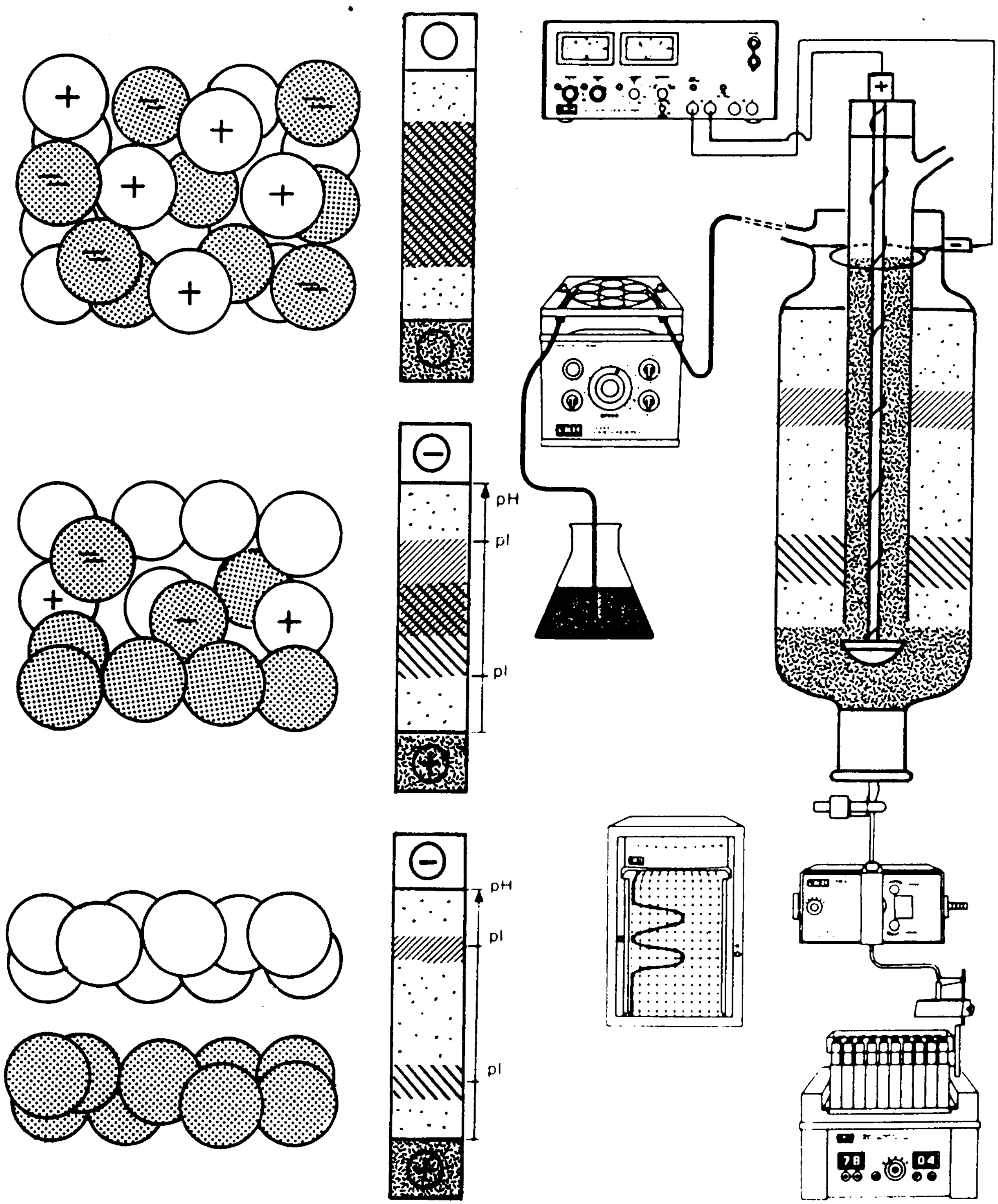


Figure 7-2. Isoelectric Focusing (IEF)

Adapted from "Materials Processing in Space Early Experiments" pg. 31 Fig. 2.20

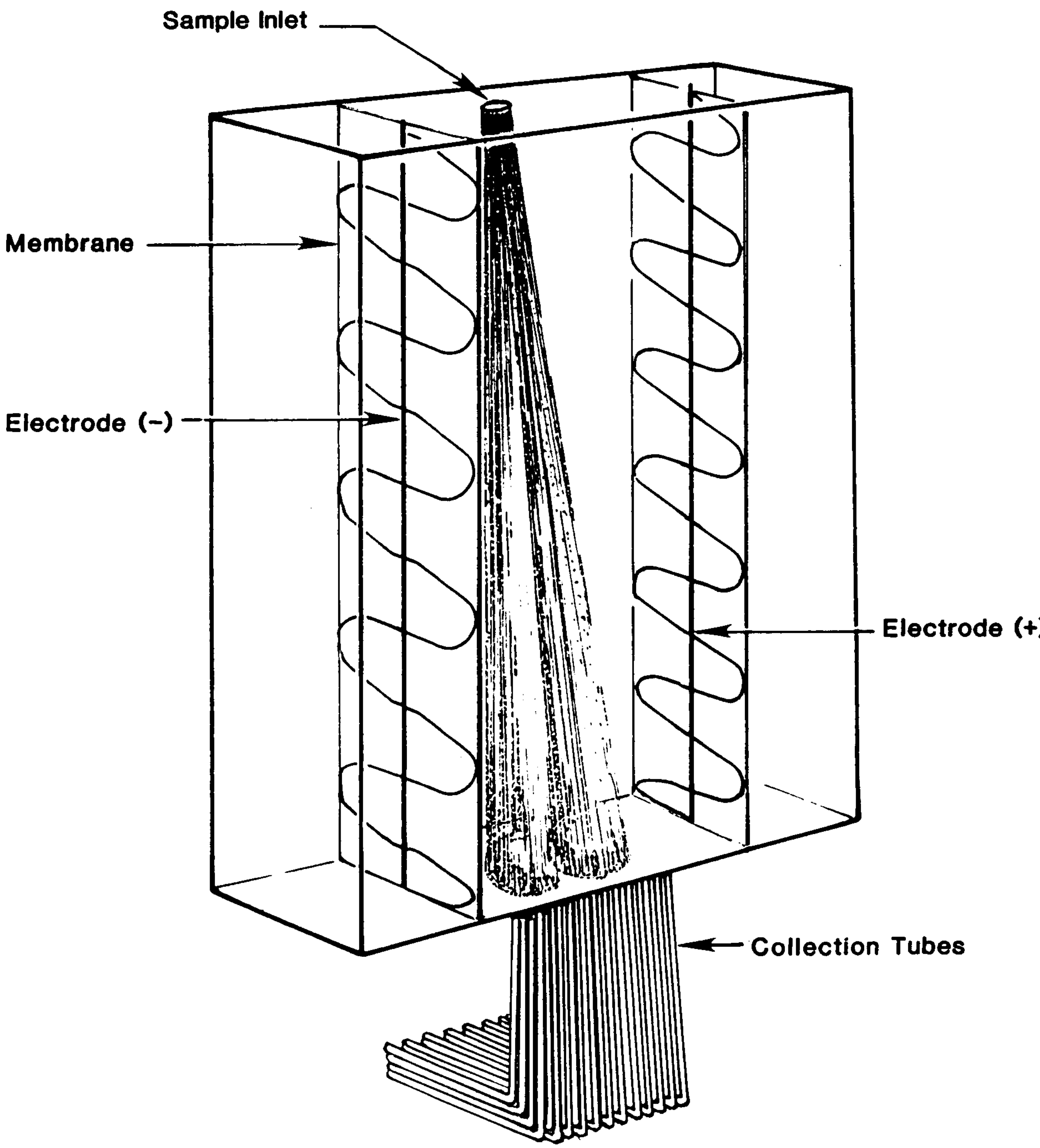


Figure 7-3. Continuous Flow Electrophesis

7.2 Crystal Growth

Single crystal silicon technology is at the foundation of the electronics industry. The production of high purity crystals devoid of imperfections and impurities is the goal of the industry. In the terrestrial processing of silicon crystals, convection currents cause imperfections. In space where convection currents and radial thermal gradients are laminated, high priority silicon crystals can be grown, for example in the high vacuum environment produced by a wake shield.

7.2.1 Semiconductors

Semiconductor crystals are used overwhelmingly in the manufacture of electronic components (chips), as digital "gates" (open or closed). The technology trend is to achieve even-greater densities of gates per unit area (gates per square mil), see Figure 7-4 (Progress of Gate Density). Desirable technical characteristics of semiconductor gates are:

- o High switching speed
- o Low switching speed
- o Uniformity of switching speed and power throughout the various gates employed in a given set of circuits (chip)
- o Low cost

A basic relationship, applicable to all linear semiconductors, connects parameters 1 and 2:

> For a uniform semiconductor, the product of switching speed (microseconds) and switching power (microwatts) is a constant, which depends only on the type of materials employed.

This product is also known as the pJ factor (pJ stands for picojoules, i.e., the product of microseconds switching time and microwatt switching power). Figure 7-5 show the behavior of these semiconductor gates.

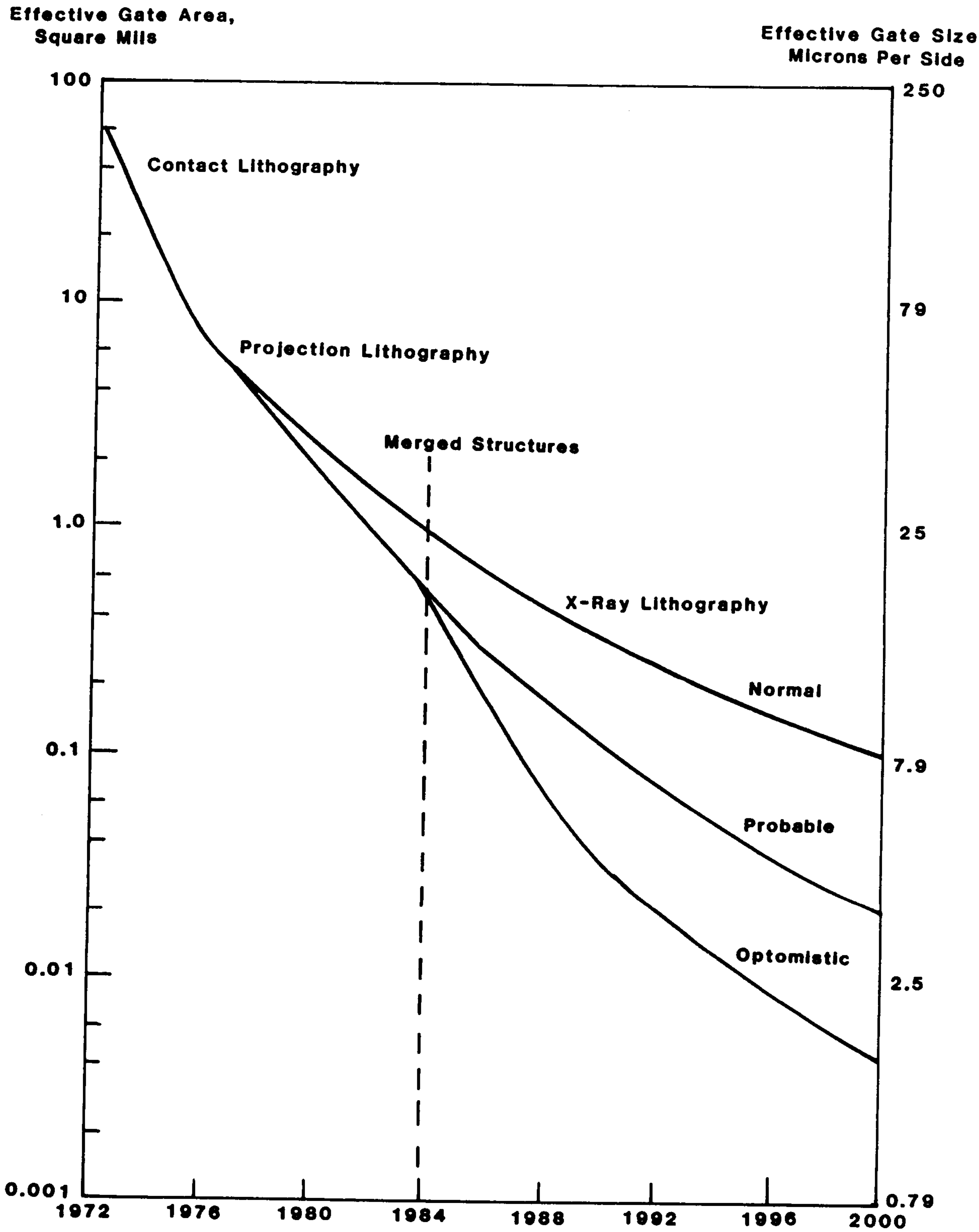


Figure 7-4. Progress of Gate Density

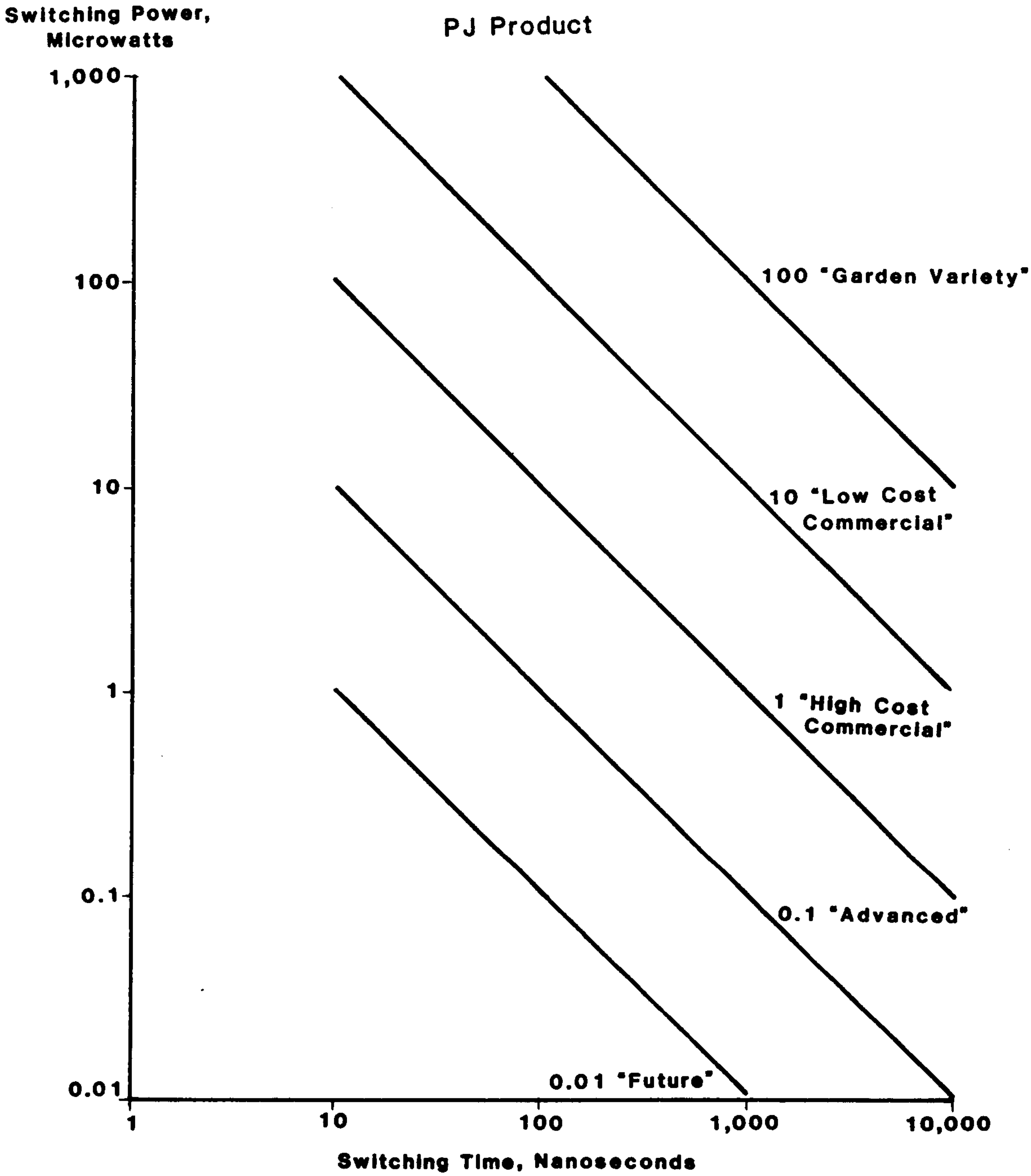


Figure 7-5. Behavior of Semiconductor Gates

The desire to reduce the pJ factor stems from obvious practical considerations:

- The drive towards greater density places increasing numbers of gates on a clip.

- This causes increased heating when these gates are driven at the shorter switching times.

- For certain applications, this excess heat can be dissipated by forced cooling (conduction, gas, liquid cooling); however, it is desirable in general to dispense with or minimize the need for cooling.

- This motivates the drive for lower switching powers.

In practice, semiconductor crystals grown in terrestrial facilities exhibit significant variations in the pJ factor among different domains (slices) of the crystal's body. These are due to microturbulences arising from the manufacturing process under one-g conditions. These microturbulences induce a lack of uniformity in the finished product, which, in several applications, either forces the manufacturers to perform "selection" procedures, or requires that the assembly of gates (chip) be driven at higher powers than would be the case with higher uniformity (because the more "sluggish" gates need to be driven "harder").

7.2.2 Vapor Transport

In the simplest vapor growth system, crystal growth occurs by physical vapor deposition. Polycrystalline material is located at one end of a closed container, or ampoule, and a small "seed" crystal may or may not be placed at the other end. The ampoule is placed in a furnace such that the end containing the source of polycrystalline material is at a temperature sufficiently high that some of the material vaporizes. This vapor fills the ampoule, and at the cooler end it condenses and returns to the solid state. The seed serves as a locus of condensation and provides the appropriate structural model for preferential crystal growth. If experimental conditions are appropriate, the crystal structure of the seed will be perpetuated during condensation and a large single crystal will be produced. If no seed crystal is used, the material condenses directly on the container wall. Nuclei are usually formed at microscopic surface imperfections on the wall, with the result that a seedless process usually produces a multitude of small crystals.

Crystals can also be grown by chemical vapor deposition, as was the case in the Skylab experiment. The difference is that the vapor is formed by chemical reaction of the source material with a transport agent at the hot end of the ampoule, and solid material is deposited when the reverse reaction occurs at the cold end. Figure 7-6 shows the crystal growth by chemical vapor transport. Again, if experimental conditions are appropriate, one or more single crystals are produced. These techniques for growth from the vapor phase are referred to as closed vapor transport, meaning that the growth ampoule is completely closed during growth. Single crystals may also be grown from the vapor phase by allowing an appropriate mixture of gases to flow through a condensation region. The depleted gas may then be exhausted or replenished and recycled. Such systems are referred to as open or flow-through systems.

7.2.3 Directional Solidification

In crystal growth from a melt, it is necessary that solidification occur in a controlled unidirectional manner. In the simplest cases, the material is contained in a cylindrical crucible that is slowly withdrawn from the open bottom of a vertical tube furnace into a cooler environment, causing solidification to proceed gradually from the lower end upward. This is referred to as the Bridgeman or Stockbarger crystal growth technique (Figure 7-7). If withdrawal is accomplished slowly and uniformly, and the initial growth is monocrystalline, the remaining material may grow as a single crystal. The probability of obtaining a large crystal is enhanced if a previously obtained small crystal (a seed crystal) is used to initiate solidification, that is, if the seed is placed in the bottom of the crucible and not allowed to melt. Other techniques are used, including crucibles with conical bottoms, to encourage initial solidification at a single point.

7.3 Containerless Processing

One of the most exciting prospects of processing materials in space is the ability to process uncontained liquids or melts. In the absence of other forces, the shape of a liquid in a weightless environment will assume a configuration that minimizes interfacial energy. For a completely uncontained liquid the equilibrium shape, or minimum-surface figure, is a sphere. In the condition of free fall the sphere remains essentially

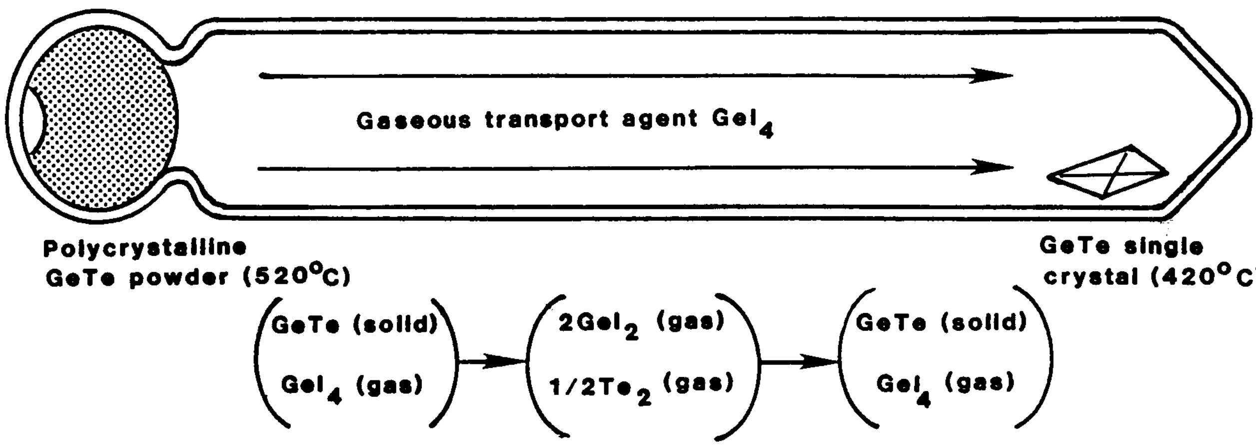


Figure 7-6. Crystal Growth by Chemical Vapor Transport

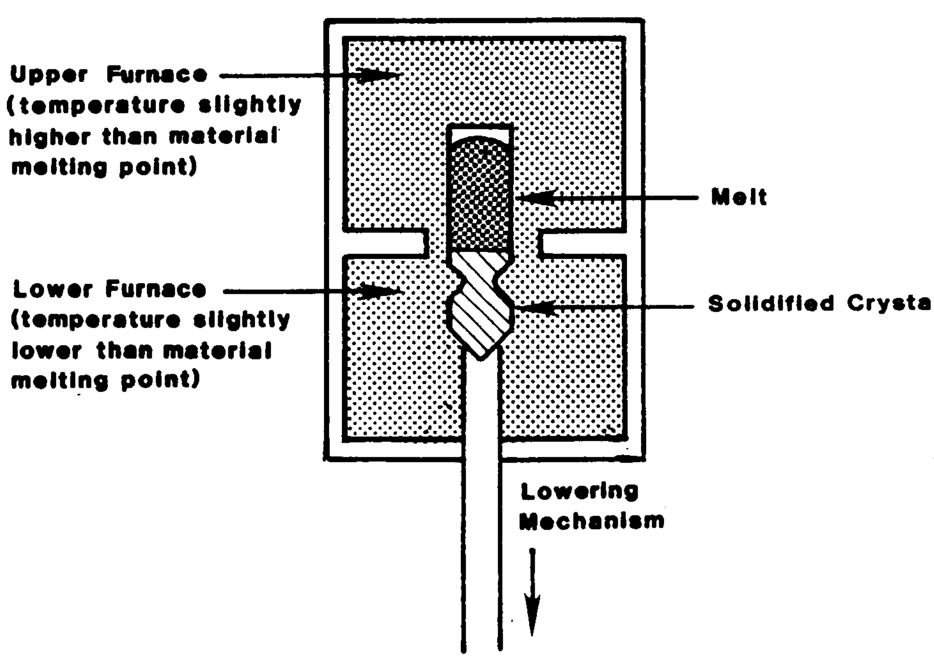


Figure 7-7. Bridgeman or Stockbarger Crystal Growth Technique

unaccelerated relative to the spacecraft. However, the small kinetic reactions originating in the slightly different trajectory of the freely floating sphere, the background jitter of the spacecraft, and the residual velocity imparted to the sphere, upon release, require an active position control if the sphere is to remain within the confines of the furnaces for any length of time.

This can be accomplished in a variety of ways. If a gaseous environment is permissible, acoustic drivers similar to loud speakers can exert an acoustic radiation pressure on the sphere. By setting up a standing wave by means of a reflector, a stable acoustic well will exist at one-quarter wavelength from the reflector, and the sphere will be retained in the center of this well provided the energies associated with the perturbing impulses do not exceed the energy of the well. Such an acoustic driver putting out 160 dB (1 W/cm^2) at 15 kHz can levitate a low-density solid sphere in Earth's gravity. However, liquid drops tend to deform and become unstable under such high-intensity sound fields. In micro gravity substantially less acoustic power is required to maintain position control. The use of three orthogonal drivers can produce three-axis positioning and by appropriate phasing can also provide rotational control.

For systems requiring a vacuum environment, electromagnetic positioning can be used provided the sample has some conductance. A radio frequency field induces a current in the sample which in turn reacts to repel the inducing field. Such devices can easily provide sufficient force to leviate a metallic sample at 1-g. However, two difficulties arise. First, the power required to levitate the sample usually produces enough heat to melt it. Hence, it is not always possible to solidify the sample in a controlled manner. Second, there is a region along the axis of the coil where the B field is perpendicular to the surface of the sample. No force is produced at this point, and when the sample melts in 1-g, hydrostatic pressure can overcome the surface tension and allow the sample to leak out.

Other mechanisms exist for position control, such as electrostatic repulsion and radiation pressure. If there were a requirement to avoid any force on the sample, a container could be literally flown around the sample by means of control jets.

One of the principal advantages of containerless processing is the elimination of wall effects such as contamination, nucleation, and induced strain. Since materials such as silicon and many of the oxide glass formers are highly reactive in the molten state (to the point of being universal solvents), considerable work has gone into minimizing container effects.*

7.4 Composite Casting

Composite casting connotes the experimentation that solidifies materials which are immiscible under normal gravity conditions. In a microgravity environment, materials with differing densities or melting points will remain suspended when solidified from a melt, making composite casting possible.

By combining previously immiscible components, materials with higher tensile strength, greater conductivity, improved pliability, or reduced weight could be produced. Section 13.2.5 discusses the potential uses of composite casting.

7.5 The Growth of Monodispersed Latex Spheres

Large monodisperse latex spheres are grown from minute "seed" particles. These "seed" particles are generated by mixing a chemical monomer, initiator, and emulsifier. The monomer is converted to latex; the initiator is the chemical that starts the reaction which is then held in suspension form by the emulsifier. Heating initiates the overall process.

Large spheres are generated from seed spheres by adding an additional monomer and initiator. When the monomer is added, the particles swell and become spongy; heat and additional initiator, harden the spheres.

Under normal gravity conditions, two phenomena tend to limit the growth of monodisperse spheres. The first is that the spheres tend to float in the initial stage of the reaction, because their density is less than that of the medium. This phenomenon is known as "creaming". The second phenomenon is that as particles grow, they become more dense than their medium and tend to settle on the bottom of the vessel. This phenomena is not a problem in small spheres because gentle stirring can be used to keep

* Robert J. Naumann, and Harvey W. Herring, Materials Processing in Space: Early Experiments, NASA, Washington D.C., 1980, pp 9-13, 51,52

the particles in suspension. However, as the size of the particles grow beyond approximately 10 micrometers in diameter, the collisions caused by increased stirring result in deformation and clustering. Additional emulsifiers can reduce this problem, but might generate spheres of divergent particle sizes.

In the microgravity of space, buoyancy and sedimentation are eliminated, reducing the need for stirring and the probability of collisions. Also, emulsifier levels required during processing can be kept low enough to avoid the generation of new particles.

As discussed in section 13.2.2, Monodisperse Latex Spheres are used in biomedical research (such as drug carriers in the body), human and animal blood flow studies, membrane and pore sizing in the body, and medical diagnostic tests; and as calibration standards for optical and electron microscopes, coulter counters, light-scattering equipment and many other types of laboratory equipment.

A special piece of hardware was developed to produce large mondisperse latex spheres in space. This device known as the Monodisperse Latex Reactor (MLR), consists of an Experiment Apparatus Container (EAC) and a Support Electronics Package (SEP). The EAC contains four separate, independently operated chemical reactors. These reactors are cyclinders, wrapped with heating tape, with stirrers for agitation and pistons for measuring volume change during reaction. Each of the reactors will produce latex from 100 cc of the chemical recipe. The SEP contains a preprogrammed micro-processor which controls the experiment operation after manual activation by the crew, and a recorder which stores all data produced during operation of the experiment.

The Monodisperse Latex Reactor was designed and engineered specifically for microgravity production of up to 50 or even 100 microns of latex spheres. The MLR was flown on five Shuttle flights, successfully producing monodisperse latex spheres of up to 30 microns with a standard deviation of 2% or less. Efforts have been initiated to develop a scaled up version of the MLR that would produce commercial levels of output.

VIII. A SYNOPSIS OF TEST FACILITIES

8.0 General

In this chapter, a synopsis of experimentally verified and planned test facilities for the commercial exploitation of the space environment is presented.

8.1 Low Gravity Test Facilities

Microgravity can be simulated on Earth for a few seconds up to a maximum of approximately seven minutes. Simulation methods may vary but the basic technique to create microgravity is to put an object in free-fall. The simplest method, as mentioned in Chapter VI, is to drop objects from elevated structures, commonly referred to as "drop towers". Alternative methods are to use specially equipped aircraft in parabolic trajectories or specially designed rockets which carry a payload into a coasting phase and return to Earth for retrieval.

There are several drop towers in this country. At Marshall Space Flight Center, there is a 30 meter drop tower which can produce 10^{-5}g for 2.4 seconds; and a 100 meter drop tower which can produce 10^{-5}g for 4.2 seconds. At the Lewis Research Center, 10^{-5}g is possible for 5 seconds.

KC-135 aircraft flying a parabolic trajectory can produce 10^{-1}g for 40 seconds or 10^{-2}g for 10 seconds. Rockets, specifically the Space Processing Applications Rocket (SPAR), can produce 10^{-4}gs for 5-7 minutes. In Figure 8-1, a profile of best attainable microgravity x duration levels, the curve labeled "Earth" represents the envelope of these values.

Because these microgravity conditions are for short durations only, the processing of materials must be on a scale in which the microgravity conditions can effectively influence the material. Table 8-1 depicts the typical size of materials which can be processed in ground based low-gravity facilities, namely small samples.

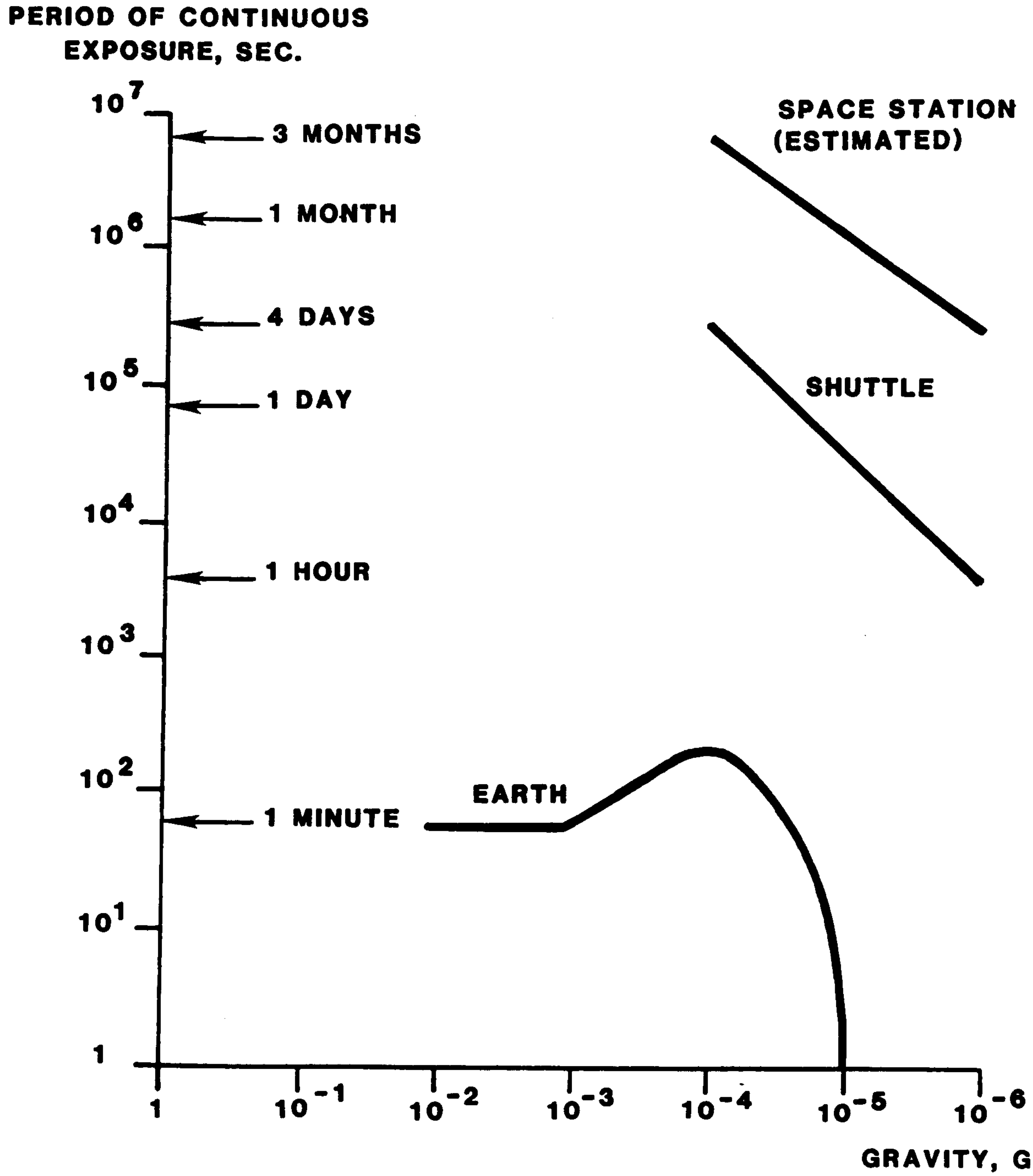


Figure 8-1. Profile of Best Attainable Microgravity x Duration Levels.

TABLE 8-1

TYPICAL SIZES OF MATERIALS SAMPLES WHICH CAN BE PROCESSED IN GROUND-BASED LOW-GRAVITY FACILITIES

FACILITY	LOW-G TIME SECONDS	SAMPLE SIZE GRAMS
30-METER DROP TUBE	2.4	0.5 TO 1
100-METER DROP TOWER	4.2	1 TO 5
AIRCRAFT	10 TO 60	5 TO 10
ROCKET	240 - 360	200 TO 300

SOURCE: COMMERCIAL APPLICATIONS OFFICE, MARSHALL SPACE FLIGHT CENTER.

In space, MPS investigations have been conducted during Apollo (flights 14, 16, and 17), Skylab, and the Apollo-Soyuz Test Project. Current testing is being performed during some Space Shuttle flights. In the mid-1980s, unmanned experimentation and manufacturing in space will be available on specially designed free-flying satellites. In the early 1990s, NASA's Space Station will be available for manned research and commercial operations.

The Shuttle can produce continuous gravity levels slightly less than 10^{-4}g for a maximum of four days. It can generate lower gravities (10^{-6}g) for shorter periods (order of 1 hour) with the help of special operational procedures. The estimated g-time duration Shuttle envelope is shown in Figure 8-2.

In theory, a Space Station could maintain continuous low gravity of at least 10^{-4}g for several months. Lower gravity levels of order 10^{-6}g could be achieved for shorter periods given the use of special operational procedures and a suitable location of the experimental equipment. The corresponding estimated space station g-time duration envelope is shown in Figure 8-1. The free-flyer missions are planned to be six months in duration achieving microgravity levels up to 10^{-5}g.

8.2 Vacuum Test Facilities

The technology for generating vacuum is well developed on Earth. Pumping devices used to evacuate lightbulbs and vacuum tubes maintain a vacuum of 10^{-6} to 10^{-8} Torr for periods of time as long as 1,000 hours. High-technology vacuum pumps can produce a vacuum of 10^{-16} Torr for up to one hour. See the curve labeled "Earth", for a profile of the best attainable vacuum x duration levels, in Figure 8-2.

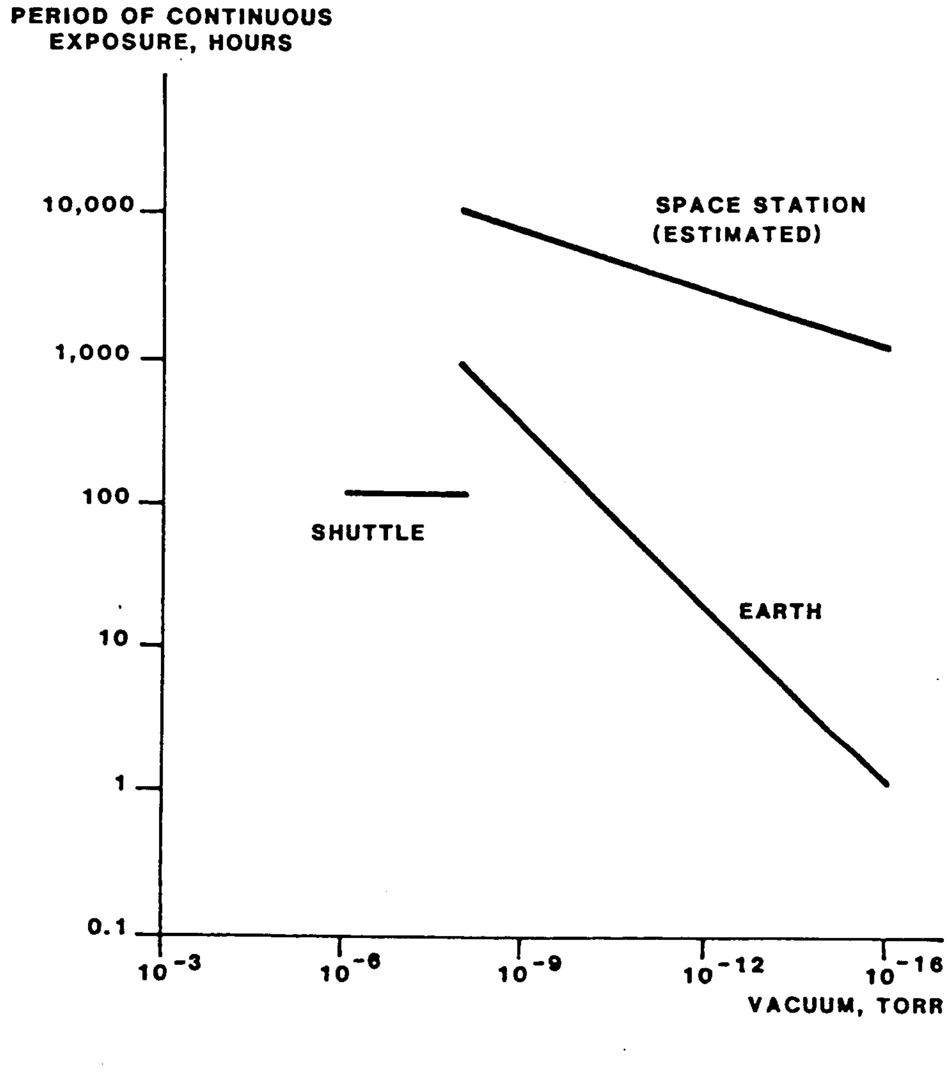


Figure 8-2. Profile of Best Attainable Vacuum x Duration Levels.

The Shuttle, because of its low orbiting altitude, can produce vacuums not greater than approximately 10^{-7} - 10^{-8} Torr 4 to 10 days (duration of a typical Space Shuttle mission).

Greater vacuums are obtainable at higher altitudes or in a Space Station equipped with special devices such as a Wake shield, shown in Figure 6-4. By virtue of its longer mission and possible higher orbital altitudes, the Space Station is estimated to be able to produce vacuums of 10^{-9} Torr for periods of 10,000 hours or more. Fitted with a Wake Shield, the Space Station should be able, in theory, to provide and maintain a vacuum of 10^{-16} Torr for upwards of 1,000 hours.

8.3 Test Facilities for Combining Low Gravity and High Vacuum

On Earth, it is difficult to produce these two effects concurrently for an appreciable length of time. The best obtainable non-orbiting facility is a SPAR flight, maintaining both low gravity (10^{-4}g for four minutes) and vacuum of up to 10^{-4} Torr, depending upon the altitude reached.

The advantage to be gained from producing combinations of low gravity and vacuum in space is in terms of the length of time in which both can be sustained simultaneously. Estimated attainable gravity-vacuum duration envelopes for both Shuttle and Space Station are shown in Figure 8-3.

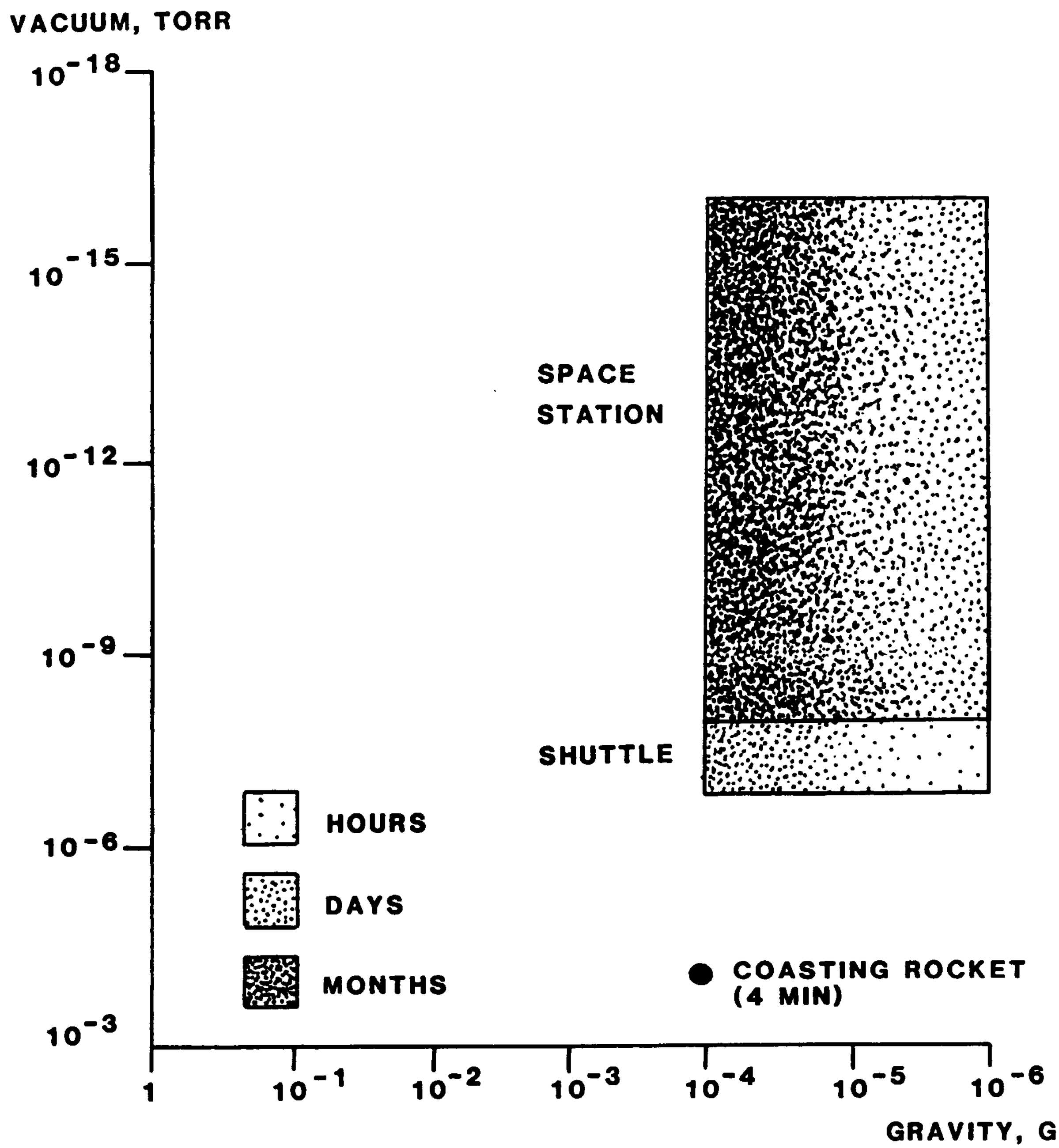


Figure 8-3. Attainable G-Vacuum - Duration Envelopes.

IX. SYNTHESIS OF MPS APPLICATIONS

9.0 Synthesis and Categorization of MPS Applications

Categorizations of MPS Applications have developed piecemeal over the last decade and a half. These categorizations grew as new applications were devised, gradually developed, and added to the inventory of actual or potential usages of MPS. The conventional categorization of MPS applications is listed in Table 9-1.

While perfectly adequate and comprehensible to scientists and engineers familiar with the field, this conventional categorization of MPS applications presents some difficulties when submitted outside this community. One of its problems is that it intermixes products, processing techniques and apparatus.

For example, the term "containerless processing" in Table 9-1 connotes a technique rather than a product. The term evinces, at first blush, exciting vistas of unique and valuable capabilities. Upon further consideration, however, one is unavoidably forced to ask "how does containerless processing relate to specific processes or products?"

The answer is not easily obtained: it requires a considerable depth of analysis.

Similarly, the category "crystal growth and solidification" connotes a set of techniques which are not unique to the space environment, but common to the manufacture of diverse products, such as semiconductors and special optical substances. One needs to engage in the mental process of assessing how this technique, when effected in space, does differ advantageously from conventional methods of growing crystals.

A more succinct grouping of conventional categories, shown in Table 9-1, has been abbreviated Table 9-2, and recently appeared in literature. While it has the virtue of conciseness, this abbreviated grouping still presents a problem for the industrial user, namely relating MPS categories to specific industrial products or processes.

TABLE 9-1

CONVENTIONAL CATEGORIZATION OF MPS APPLICATIONS

- Crystal Growth and Solidification
- Electrokinetic Separation
- Fluid Mechanics
- Composites
- Suspensions
- Immiscible Systems
- Solidification Front Interactions
- Monodispersed Latex Spheres
- Critical Phase Transformations
- Floating Zones
- Distortional Influences
- Containerless Processing
- Degassing and Desorption
- Extensive Electron Beam Processing

TABLE 9-2

ABBREVIATED CONVENTIONAL CATEGORIZATION OF MPS APPLICATIONS

- Crystal growth
- Solidification of Metals, Alloys and Composites
- Fluids, Transports, and Chemical Processes
- Ultra High Vacuum and Containerless Processing Technologies

9.1 Alternate Categorizations

As is the case with all new sciences, MPS Categorizations have grown through an inductive process. Diverse findings and ideas gradually emerged and accreted to the body of MPS knowledge.

The natural evolution of a maturing science is to eventually transition from the inductive to the deductive approach to knowledge, i.e., from the particular to the general, from a collection of facts to the definition of underlying and unifying "laws".

The advantage of the deductive approach is that it permits the philosophically satisfying process of explaining the available facts; further, and more useful in practice, it allows the prediction of the ultimate consequences of "laws" and thus serves to guide subsequent research towards approaching the ultimate limits of which the technology is capable.

At this time, MPS appears to be sufficiently mature to lend itself to such a process of deductive categorization.

A deductive categorization of MPS functions should begin with principles, i.e., with the ultimate objectives of MPS; it should progress subsequently to its applications, through an analysis of the exploitable properties of the space environment, following an ordered sequence of logical steps.

The end applications derived from this approach should satisfy five criteria:

- o Orthogonality, i.e., the applications should not overlap each other
- o Comprehensiveness, i.e., the method should encompass the spectrum of current and potential future applications
- o Traceability, i.e., the genealogy of each application should be unequivocally relatable to the objectives through each step of the logic
- o Visibility, i.e., the logic should allow facile communication and understanding on the part of recipients not fully conversant with the field
- o Significance, i.e., the end results should be expressible in terms related to economic value

Figure 9-1 illustrates a reconciliation of current categorization of MPS application, derived from the top-down approach, introduced in Section 6 (Figure 6-1).

This scheme reconciles the current categorization with a deductive classification. The scheme represents a science-oriented approach, useful to technologists for categorizing actual or potential MPS products in terms of the space environmental effect, or a combination of effects, utilized to generate them.

A more industrially-oriented categorization, by objective, is depicted in Figure 9-2. Its logic derives from two top-level objectives:

- o The development of materials having specified characteristics

- o The development of material-producing processes which are economically worthwhile, i.e., efficient in terms of the required resources

These two objectives have been the goal and have permeated the evolution of materials processing throughout mankind's history.

In pursuit of the first objective, for example, stone implements have been gradually replaced by bronze, iron and then steel; bark bowls have given way to earthenware, porcelain, and plastics; medicinal herbs have been superseded by potions, inorganic pharmaceuticals and finally antibiotics. In all cases, new developments in materials technology have evolved through improved understanding of how to control the properties of the corresponding substances.

The second objective listed above addresses the obvious requirement for economic efficiency. The occasional lumps of iron produced in Sumerian copper smelters became of practical use only after the Hittites discovered how to produce the metal at sufficiently low cost to warrant replacing their army's bronze swords. Aluminum, worth more than gold before the inception of this century, became a major element of modern technology only after the economical process of cryolite electrolysis was developed.

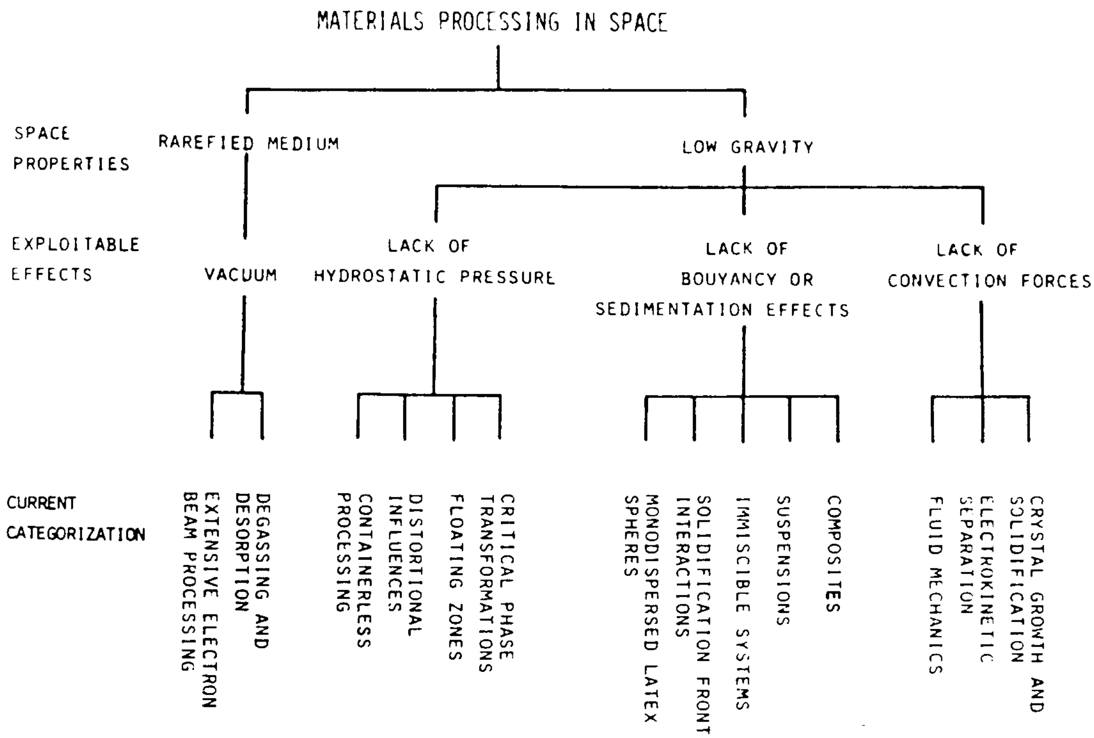


Figure 9-1. Reconciliation of Current Categorizations of MPS Applications with Top-Down Approach

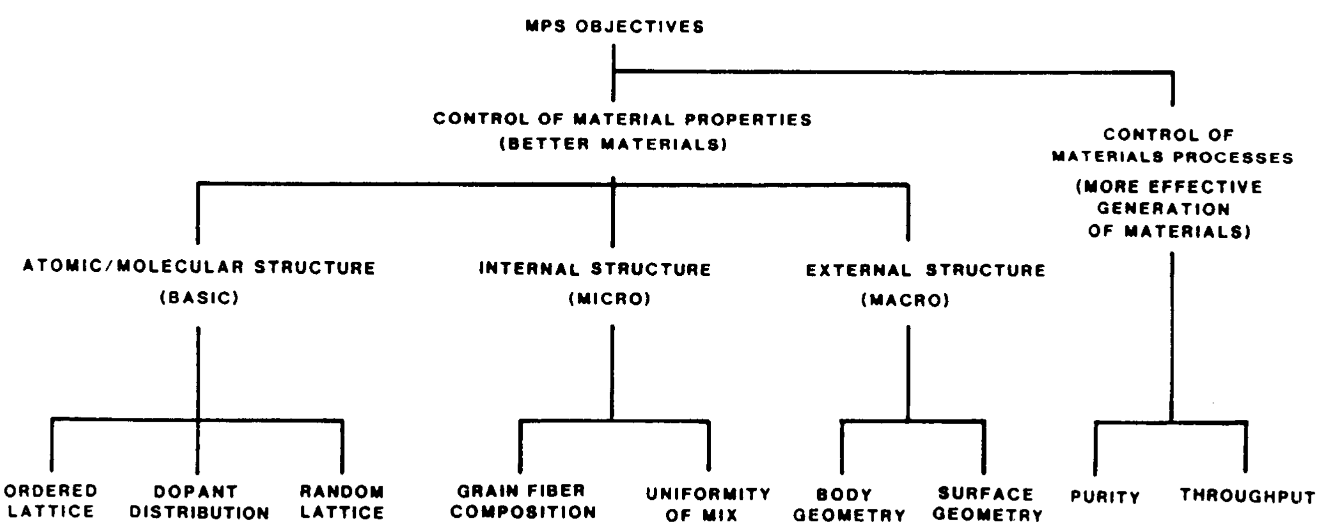


Figure 9-2. Materials Processing in Space-Categorization by Objectives

The two objectives stated above correspond to the two top-level branches shown in the logic tree of Figure 9-2, labeled respectively: Control of Materials Properties and Control of Materials Processes.

Modern materials technology seeks to control the properties of materials at three levels:

- o The atomic or molecular structure -- Control of materials properties at this level represents the highest degree possible for practical control to date.* Such structural control is ultimately desirable for most materials. However, because of its difficulty and expense, it is currently exercised for products only where its use is of paramount necesssity.

  Control at the molecular level is required: 1) for generating highly ordered lattices used, for example, as building substrata for semiconductors; 2) for achieving distributions of suitable "impurities" (dopants) in exact proportions and at precisely determined locations within ordered lattices in order to produce high-quality semiconductors; or 3) for accomplishing highly random distributions of atoms and molecules, needed for producing the category of materials conventionally known as "glasses".

- o Internal macromolecular structure -- Control at this level involves the distribution or alignment of groups of molecules. This type of control is attempted in the metallurgical industry, for example, to achieve desired proportions and spatial distributions of hard perlite grains within softer iron-carbon matrices. Concentration of hard grains at the surface of the internal parts of machines provides resistance to wear; the softer material throughout the rest of the machine provides resilience to impact. Also, grain and fiber control is used to achieve uniform or pre-assigned distributions of two or more materials, each having specified grain sizes which are immiscible in bulk.

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* Control at the subatomic level is a logical next step of the advancing MPS technology. It has not as yet appeared in current literature.

- o <u>External structure</u> -- Control at this level defines the shape of macroscale objects. The intent of this type of control is to provide exact geometrical shapes -- e.g., perfect spheres -- and/or preassigned surface finishes. Examples are ball bearings, microspheres, electrical contacts.

It is clear that the three levels of control defined above can be attained jointly.

For example, machine parts almost always couple controlled internal grain structure with precise external dimensions. Such combinations are conventionally achieved by serial processing. One of the exciting promises of MPS is the possibility of accomplishment by means of a single processing operation -- for example, through containerless processing.

In addition to striving for control of materials properties, modern industrial technology seeks to continuously improve the economics of materials processes. This important facet of MPS is indicated by the right-hand branch of the logic tree of Figure 9-2.

MPS technology offers two opportunities for improving processes:

- o Manufacturing in the space environment, and

- o Experimenting in the space environment

The first opportunity applies to situations where the value of the end-product is sufficiently high, and the improvement of processing efficiency is sufficiently significant to more than offset the transportation costs to and from space. The second opportunity applies in cases where three driving factors are present: 1) conventional terrestrial manufacturing processes are not clearly understood; 2) improved understanding can lead to significant reduction in the costs of the product; and 3) the sales of the products are sufficiently conspicuous so that even modest savings in processing costs would more than offset the expense of space experimentation.

The classification proposed and shown in Figure 9-2 appears to meet the criteria of usefulness outlined previously. The classification scheme is orthogonal; there is no overlap among functions. The classification is comprehensive because all classes of materials, e.g., glasses, semiconductors, ceramics, metals, composites, polymers and complex biochemicals, fit into one or more of the control schemes. Traceability is preserved because each material can be connected to a specific class of control and related back to the objectives of MPS.

This type of categorization, by virtue of its orientation towards "what to do", serves to focus one's perception onto the MPS application of particular interest.

Note that the proposed categorization eliminates items which connote techniques or apparatus, e.g., "containerless processing". The latter fall within the realm of "how to do" rather than "what to do". They belong in a subsequent phase of MPS consideration, dealing with which specific choice of technique to employ in attempting to achieve the industrial customer's materials control objective.

9.2 Results of MPS Programs to Date

The time span of available results is from 1968 to 1983. Prior to the Space Shuttle, approximately 130 MPS-oriented experiments and tests were conducted by the U.S. for a total of approximately 30 hours of low-g exposure. These experiments and tests are summarized in Appendix A. Appendix B summarizes the available results of Shuttle MPS experiments. These summaries were derived from existing published literature. For each investigation, the following information is provided:

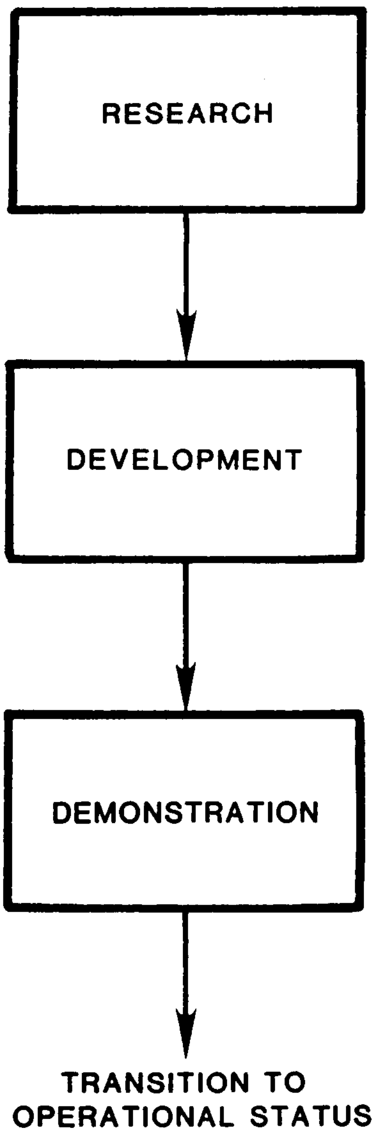
- Title of the investigation as assigned in the literature
- Name and organization of the Principal Investigator (PI)
- Vehicle on which the investigation was conducted, e.g., ground, rocket, Skylab
- Time frame when the investigation was conducted
- Objective of the investigation
- Results accomplished

Of significance to the overall MPS program is the current status of the investigations, in terms of progress through the successive steps of research, development and demonstration. The scheme of categorization or stages of progress toward commercialization is shown in Figure 9-3. With reference to this Figure, note that the goal of research is to define, modify and verify a concept which holds promise for MPS. The objective of development is both descriptive and predictive, resulting in the verification of a concept suitable for commercial demonstrations or suggesting new approaches for research to modify the concept. The purpose of commercial demonstration is to show that the processing concept works on a larger scale, that processing is economically attractive and that the market exists for the corresponding product.

The investigations listed in Appendix A were categorized as to the stage of progress toward commercialization and are presented in Figure 9-4. Note that only two experiments could be classified as pilot-scale demonstrations. The one listed in the column "absence of convection" demonstrated free-flow electrophoresis. The other listed in the column "absence of buoyancy-sedimentation" demonstrated the manufacture of large monodispersed latex spheres.

Comparison of the "categorization by objective" of Figure 9-2, and the "categorization as to progress" of Figure 9-4, leads to a broad hypothetical inference relative to potential commercialization of MPS materials, namely, that product candidates for commercialization will likely reach fruition in those applications requiring control of the macroscopic structure of a material or process. Thus, electrophoresis, which appears closest to commercialization in Figure 9-4 (under the heading "absence of convection" and "pilot demo"), fits under the right-most column "control of material processes" of Figure 9-2. The microsphere experiment, also close to commercialization (see Figure 9-4 under the headings "absence of buoyancy sedimentation" and "pilot demo"), fits in Figure 9-2 within "body geometry" under "external structure". Both these categories connote control of materials properties on the largest (macro) scale. Experience thus appears to indicate that control is most difficult for the smaller scales, and less difficult as the scale of the product increases.

Almost two-thirds of the investigations tabulated in Figure 9-4 lie in the research category. For most of these, the Principal Investigators did not provide explicit results.



- Concept Definition
- Theoretical Modeling
- Experiment Design
- Experimental Verification on Ground

- Design of Test Apparatus
- Replicable Experimentation to Validate Applicability to Space Processing
- Experimental Application of Theory to Demonstrate Predictability of Results Across Range of Conditions/Materials

- Design of Pilot Unit
- Operation of Pilot Unit
- Economic Analysis to Verify Commercial Potential
- Market Stimulation

Figure 9-3. Stages of Progress Towards Commercialization

		RESEARCH	DEVELOPMENT		DEMONSTRATION	
			EXPERIM. DATA	EXPERIM. APPARATUS	PILOT DEMO.	PROCESSING APPARATUS
LOW GRAVITY	Absence of Hydrostatic Pressure	21	7	5	-	2
	Absence of Convection	28	19	-	1	2
	Absence of Bouyancy/ Sedimentation	25	15	-	1	
RARIFIED MEDIUM	Vacuum	3	-	-	-	

Figure 9-4. MPS Experimentation Categorized by Stage of Progress Towards Commercialization (Through September 1982)

Shuttle Borne experiments, Appendix B, is categorized according to the methodology in Section 9.3. See Figure 9-5 for its stage of progress toward commercialization.

Demonstration of Processes	Experimental Data Points	Theoretical Analysis	Process Developments
5	39	0	5

Figure 9-5. Shuttle Borne Experimentation Categorized by the Stages of Progress Toward Commercialization

9.3 Methodology for Synthesis of Results

The methodology follows the approach outline below.

Step A. The MPS investigations are subdivided by categories following the approach presented in Figure 9-3. Analysis of the approximately 130 pre-Shuttle investigations summarized in Appendix A indicates that they fall into four categories in descending order of achievement of "hard" results:

1) Demonstrations of processes. These are tests, or series of tests, aimed at defining the technical and economic characteristics of specific MPS processes and/or products; for example, the series of electrophoresis processing tests performed on the Space Shuttle;

2) Experimental data points collected in a low-gravity (and/or vacuum) facility. In this category fall experiments aimed at demonstrating specific effects of the space environment, postulated by theory; for example, Skylab tests to validate the fact that convection does not operate under weightless conditions;

3) Theoretical analyses — for example, the extensive series of researches performed by the Bureau of Standards under contract to NASA;

4) Process technology or equipment developments necessary to enable precise measurements or collection of data unique to the space environment. These include special studies and techniques for the transfer of processes to Earth-based systems.

Step B. For each category of investigation defined above, the corresponding report material was analyzed to determine which of the following elements of information have been yielded by each investigation:

1) Results indicating a major technical and a promising economic advantage of processing in the space environment;

2) Results indicating an experimentally proven advantage of the space environment;

3) Results indicating a definite theoretical advantage of the space environment;

4) Inconclusive results observed, despite an apparently correct experimental procedure;

5) Inconclusive results due to a faulty experimental procedure. Typical of this case is the documented occurrence, or the suspicion of occurrence, of spurious spacecraft maneuvers which have interfered with an experiment. An example is the "sphere forming" low-gravity experiment in Skylab;

6) Definitively negative results. This would imply that the hypothesis postulated for the investigation has unquestionably been proven faulty. Note that very few, if any available experimental findings are expected to fall into this category;

7) Results not available or proprietary

X. THE NASA SHUTTLE PROGRAM

10.0 Overview

NASA's Shuttle Program has significantly expanded the scope of microgravity research. In three years, ten flights have been conducted; of these, all but the first two carried MPS experiments. One Mission, STS-9, was dedicated to the ESA's Spacelab 1, which contained among other experiments, 30 devoted to MPS. Two experiments--the Monodisperse Latex Reactor (MLR) and the Continuous Flow Electrophoresis System (CFES)--were each conducted on five of the ten Shuttle missions. These two experimental programs show substantial promise, and steps are being taken to scale up the hardware associated with these experiments, in order to produce commercial levels of output. (See Chapter XIII for details).

10.1 Pre-Shuttle Research Limitations

The Shuttle Program has removed many of the restraints that existed in microgravity research.

Prior research was restricted by several complex factors such as:

- limited duration of exposure to microgravity
- limited available power for experimentation
- limited involvement by Scientists in actual experiments on manned space missions

Only short durations of microgravity--3 to 5 seconds in drop towers and 4 to 6 minutes on SPAR flights--can be achieved in ground based facilities. For many experiments, such as alloying investigations, this short duration of exposure restricts investigations to small sample sizes to insure that the microgravity conditions effectively influence the material.

The availability of power directly affects both the size of samples and the range of usable elements in microgravity research. For example, in crystal growth and alloy experiments, maximum furnace temperature and the field of elements that may be melted are dependent upon access to electrical power. On Apollo flights 14, 16, and 17, electrophoresis experiments, which require electrical power to determine separation rates and sample sizes, were restricted to the use of power available through an electric shaver outlet.

Prior to the Shuttle flights scientists could not directly perform their experiments in space; astronauts were trained to operate hardware systems. As a result, the expertise of the scientist specialist could not be tapped at the actual experiment site.

10.2 Shuttle Services Currently Available

Shuttle missions, as a platform for space-based research, have expanded the potential duration of exposure to microgravity from a few minutes in ground-based operations to ten days in space. The power available for these missions is considerably greater than that available to researchers on previous manned space missions. In addition, Shuttle flights provide Scientists with the opportunity to conduct experiments in space.

The Shuttle includes several MPS projects in its agenda. These range from low cost, self-contained systems to state-of-the-art technology hardware controlled by scientists. In addition, the Tracking and Data Relay Satellite System (TDRSS) communications links now make it possible to establish a ground to Shuttle hook-up. Thus, experimental data may be transferred directly to sophisticated ground computer systems, reducing excessive hardware requirements.

Several Shuttle programs offer research opportunities for MPS. These programs, listed below, will be briefly examined in the following sections.

- Long Duration Exposure Facility (LDEF)
- Mid-deck Payloads
- Get Away Specials
- Materials Science Laboratory
- Spacelab
- MPS Satellites

10.2.1 Long Duration Exposure Facility (LDEF)

The LDEF, a large, unmanned, free-flying structure, is capable of accommodating numerous experiments requiring long exposure to the space environment. It will be lifted into space in the cargo bay of the Shuttle and placed into orbit for six to nine months before being retrieved and returned to Earth by a later Shuttle flight.

The purpose of the LDEF is to study the effects of exposure to space on various materials and processes. The availability of power for MPS applications, however, is limited in the LDEF.

As shown in Figure 10-1, the LDEF is a twelve sided regular polygon, 30-feet in length and 14 feet in diameter. It will hold up to 86 experiment trays: 72 on the periphery and seven at each end. The trays are 50 inches x 38 inches and can be 3, 6 or 12 inches deep. Each tray can carry one to six experiments with a total combined weight of up to 175 pounds.

The first launch of the LDEF on STS-13 in April 1984 carried an MPS experiment for crystal growth study of lead sulfide and calcium carbonate.

10.2.2 Middeck Payloads

The Middeck areas of the Shuttle Orbiter have a limited capacity to accommodate scientific payloads. Certain requirements in terms of weight, volume, cooling and power capacity, however, must be met.

MPS experiments have been carried in the Middeck area of seven of the first ten Shuttle flights. Two programs, in particular--The Monodisperse Latex Reactor and the Continuous Flow Electrophoresis System--have been concentrated in this area. Each of these experimental programs was flown on five separate missions. Details on the results of these experiments can be found in Appendix B, and a further discussion of these two programs can be found in Chapter VII.

The addition of the Middeck area for experimentation facilitates involvement and extends operations to periods longer than those available before the Shuttle program.

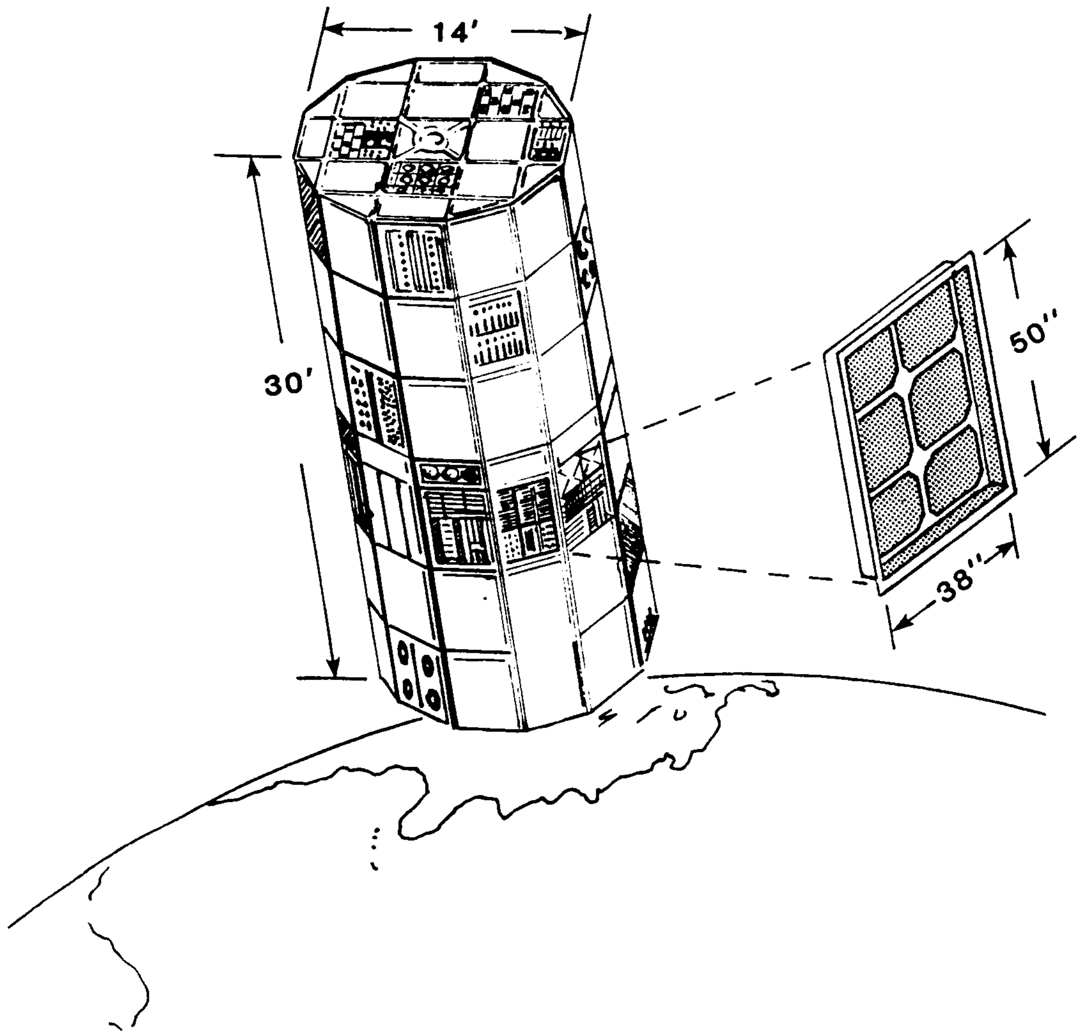


Figure 10-1. Long Duration Exposure Facility (LDEF)

Experiments can be placed in this area just prior to launch and removed expediently upon flight return.

Forty-two standard storage lockers are located in the Middeck Payload area (Figure 10-2). Some of these lockers are available for experiments: the MLR used three of these. Each locker is 20x17x10 inches or approximately 2 cubic feet. They may be used to house experiment hardware or be removed to make room for specially designed hardware which would mount to the wall adapter plates.

10.2.3 Get Away Specials

Get Away Specials are small, experimental containers that fit into excess payload space in the Shuttle Orbiter Cargo Bay. They allow NASA to sponsor low cost experiments for interested individuals and organizations.

These containers are available in two sizes: 20x14 inches (2 cubic ft); 14x28 inches (5 cubic ft). Three weight categories are available: 60, 100, and 200 pounds. Costs are broken down by these container sizes and weights; they range from $3,000 to $10,000.

Get Away Specials provide the most inexpensive opportunity to conduct experiments on board the Shuttle Orbiter. These experiments, however, must be self-contained, providing their own power. Canisters may be sealed with an inert gas or vented to expose the experiment to the elements of space. Some interaction from the crew may be possible, but is limited to simple inputs such as turning a switch on and off.

Requests for Get Away Specials are accepted on a first come first served basis and the response to this program has been tremendous. Accepted experiments range from high school studies of plant growth in space to MPS studies of crystal growth.

Overall, Get Away Specials offer an excellent opportunity to cost effectively test, on a small scale, the effects of processing in space.

10.2.4 Materials Science Laboratory

The Materials Science Laboratory is a self contained unit carried in the cargo bay of the Shuttle Orbiter. It is designed to perform MPS experiments that allow in-flight monitoring.

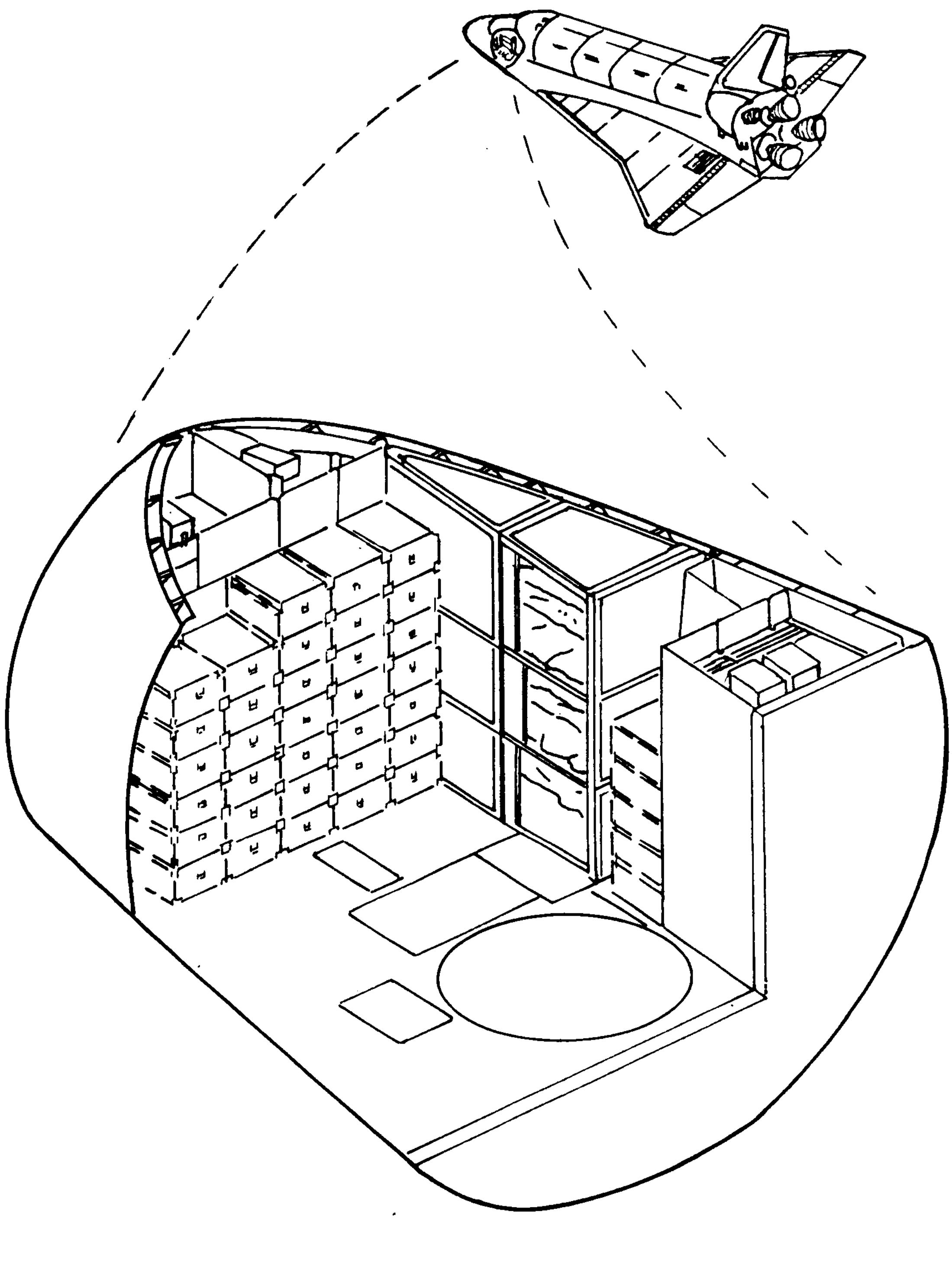


Figure 10-2. Middeck Payloads

The unit, shown in Figure 10-3 is made up of a Materials Experiment Assembly (MEA) and gas containers mounted for MPS. This system is reusable and flights are planned on a six to nine month schedule.

The MEA requires only on/off commands from the Orbiter and transmits its operational status back. The experiment mass is approximately 1500 kg out of a total mass of approximately 2,400 kg.

The first Materials Science Laboratory (MSL 2) flight is scheduled for August 1985 on STS-27.

10.2.5 Spacelab

With the deployment of the research laboratory, Spacelab, scientists are able to conduct research in space in conjunction with the work of astronauts.

Spacelab was designed and built by the European Space Agency (ESA) in cooperation with NASA. It is a modular facility flown into space and returned to Earth in the cargo bay of the Shuttle Orbiter. Scientists, included among the Shuttle crew, conduct research in the "shirt sleeve" environment of this laboratory.

Spacelab is augmented by the Tracking and Data Relay Satellite System (TDRSS), which provides a high speed data link with ground-based information systems. Fitted with highly sophisticated hardware, Spacelab is amenable to a broad range of research.

Spacelab I opened new horizons for research in seven disciplines:

- Atmospheric physics
- Earth Observations
- Space plasma physics
- Materials Science Technology
- Istronomy
- Solar Physics
- Life Sciences

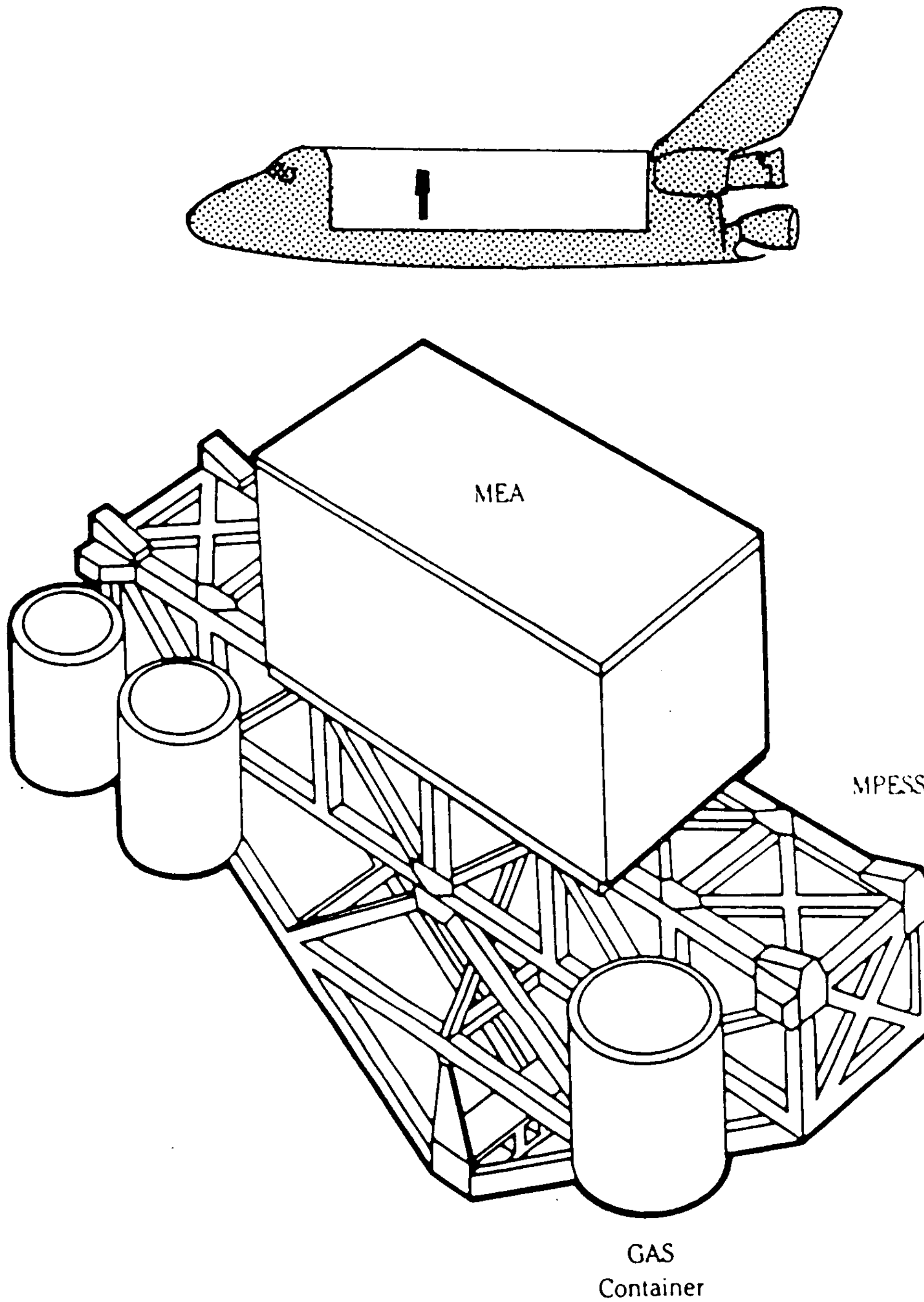


Figure 10-3. Materials Science Laboratory

A description of Spacelab equipment and operational capabilities is outlined in Chapter 11.

10.2.6 MPS Satellites

Unmanned MPS Satellites are another potential spinoff of the Space Shuttle program. Lifted into orbit by either the Shuttle or an expendable launch vehicle, these satellites would remain in orbit operating for six to nine months before being retrieved and returned to Earth by a Shuttle Orbiter.

Two MPS Satellites are currently planned for deployment about 1987. Fairchild Industries, a U.S. based company, is developing "Leasecraft"; The European Space Agency is developing "EURECA." Figure 10-4 shows a preliminary sketch of these two free-flyers.

High cost advantages and research dividends are expected from these MPS Satellites. Chapter 12 provides an overview of both "Leasecraft" and "Eureca".

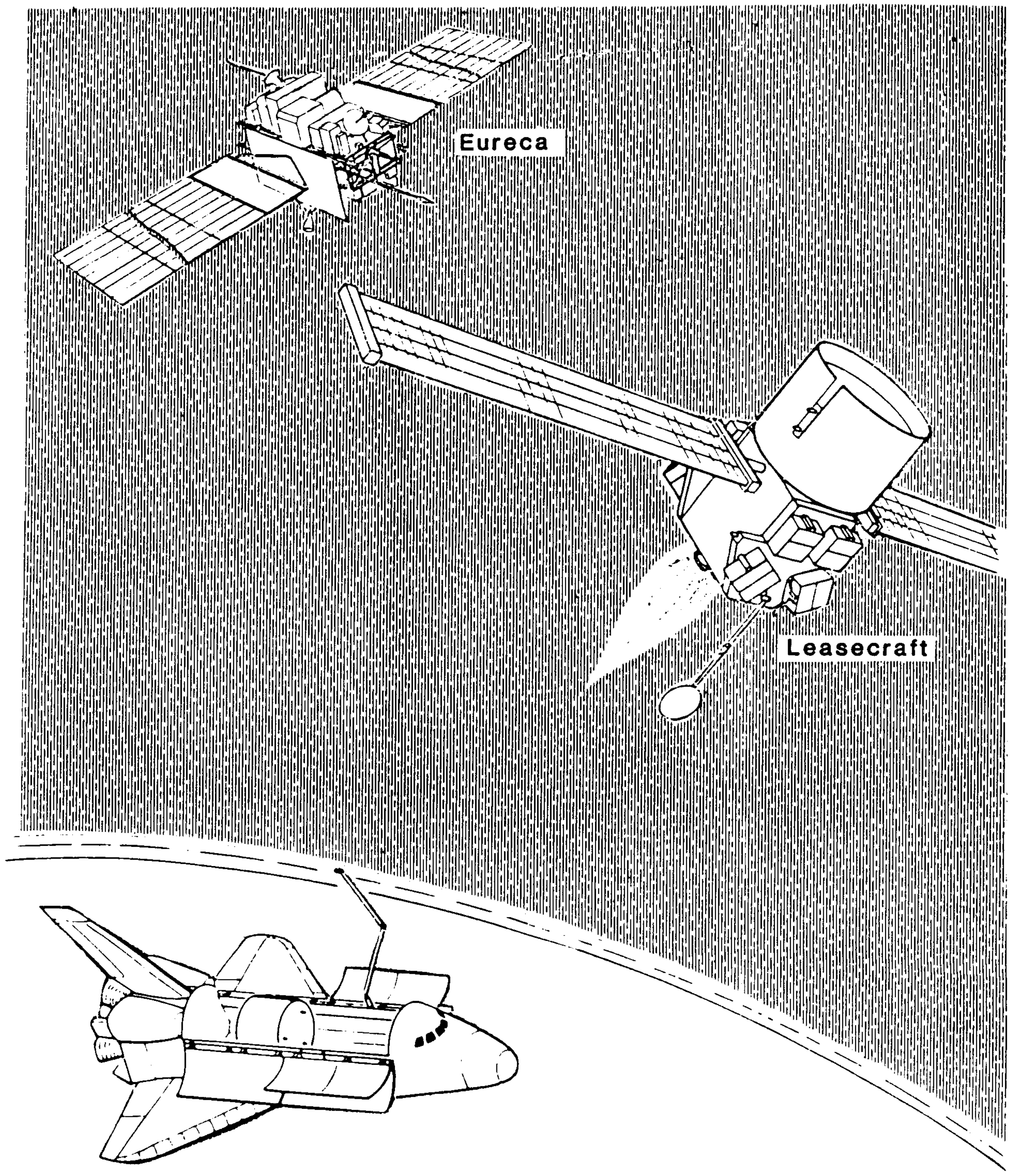


Figure 10-4. Eureca/Leasecraft

XI. SPACELAB

11.0 Background

From the beginning of the space program, achievements in microgravity and remote sensing studies have suggested the untapped potential of space research. Skylab briefly capitalized on this potential, but the transfer of personnel, equipment and hardware necessary to effectively utilize this facility became cost prohibitive. The Shuttle program represents an efficient method of transporting personnel and hardware into space to conduct space-based research and then return to Earth. Spacelab, as an outgrowth of the Shuttle program, offers Scientists the first opportunity of performing cost efficient, hands-on research in space.

Designed and built by the European Space Agency (ESA), Spacelab is a modular, reusable laboratory, to be carried in the cargo of the Shuttle. NASA is responsible for the management of all Spacelab flights. Potential users may contact NASA to arrange experiments; costs for these experiments will be tied to Shuttle launch and operations costs.

11.1 Component Parts

Spacelab is a modular facility which allows experiments and support hardware to be removed, exchanged, or rearranged in a number of combinations to fit the needs of the users. The hardware weight, size, power, and data handling capabilities now available to researchers on manned space missions have been extremely broadened over pre-Shuttle missions.

There are three basic parts to the Spacelab system:

- o cylindrical pressurized habitable module
- o tunnel
- o "U"-shaped equipment pallet

See Figure 11-1 for a Spacelab overview.

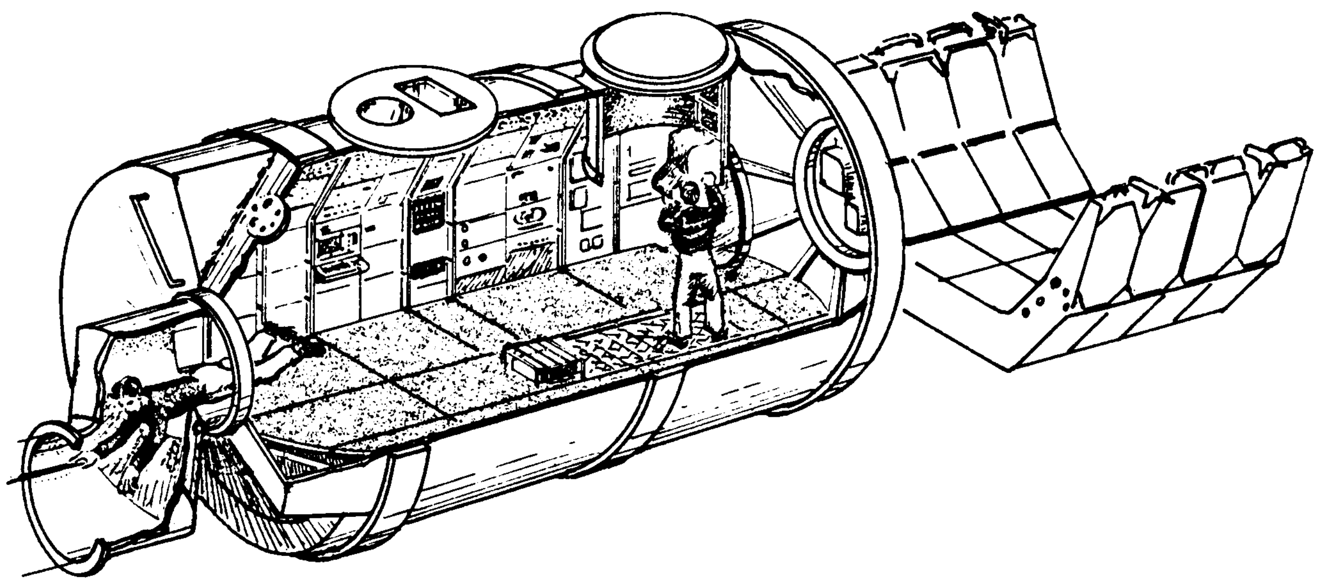


Figure 11-1. Spacelab: Habitable Module, Tunnel and Pallet

The cylindrical pressurized module is the habitable working area for the crew. It is both a pressurized facility providing a shirtsleeve environment for the crew and laboratory housing racks of custom made instruments, equipment and a workbench. The module is available in two sizes:

- o long module, and
- o short module.

The long module is made up of two short modules, approximately 13 feet (4m) wide and 11.5 feet (2.7m) long. Thus, the long module is approximately 23 feet long and 13 feet wide.

The U-shaped equipment pallet holds those experiments which require direct exposure to space or those that do not require a normal atmosphere in which to operate. All of these experiments are easily monitored, and controlled from the habitable module. The U-shaped equipment pallet is approximately 10 feet (3m) long and 13 feet (4m) wide.

The pallet igloo, shown in Figure 11-2, is a cylinder which houses those support subsystems that require a normal atmosphere in which to operate. It provides $2.2m^3$ of auxiliary space.

11.2 Configurations

The Spacelab configuration modular elements can be arranged to meet user needs. Eight basic flight configurations, shown in Figure 11-3, have been established for Spacelab. Five of these configurations use habitable modules, with or without pallets, three use pallets only.

11.3 Communications Data Link

Through the use of an elaborate world wide communications network, Spacelab will be linked up with sophisticated ground-based computers. The elements of this network are the Tracking and Data Relay Satellite System (TDRSS), the Ground Space Tracking and Data Network (GSTDN), and the Spacelab Data Processing Facility (SLDPF).

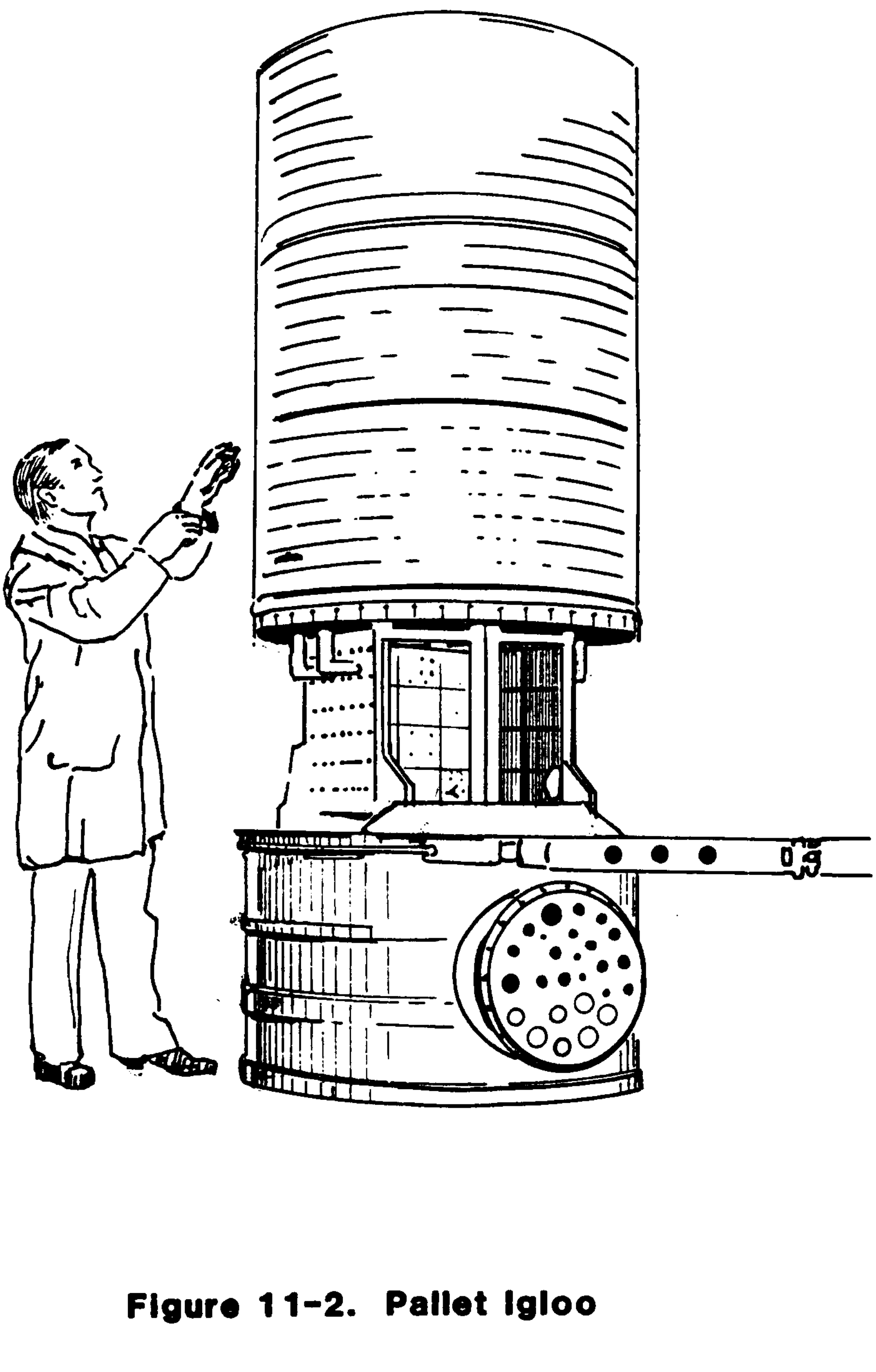


Figure 11-2. Pallet Igloo

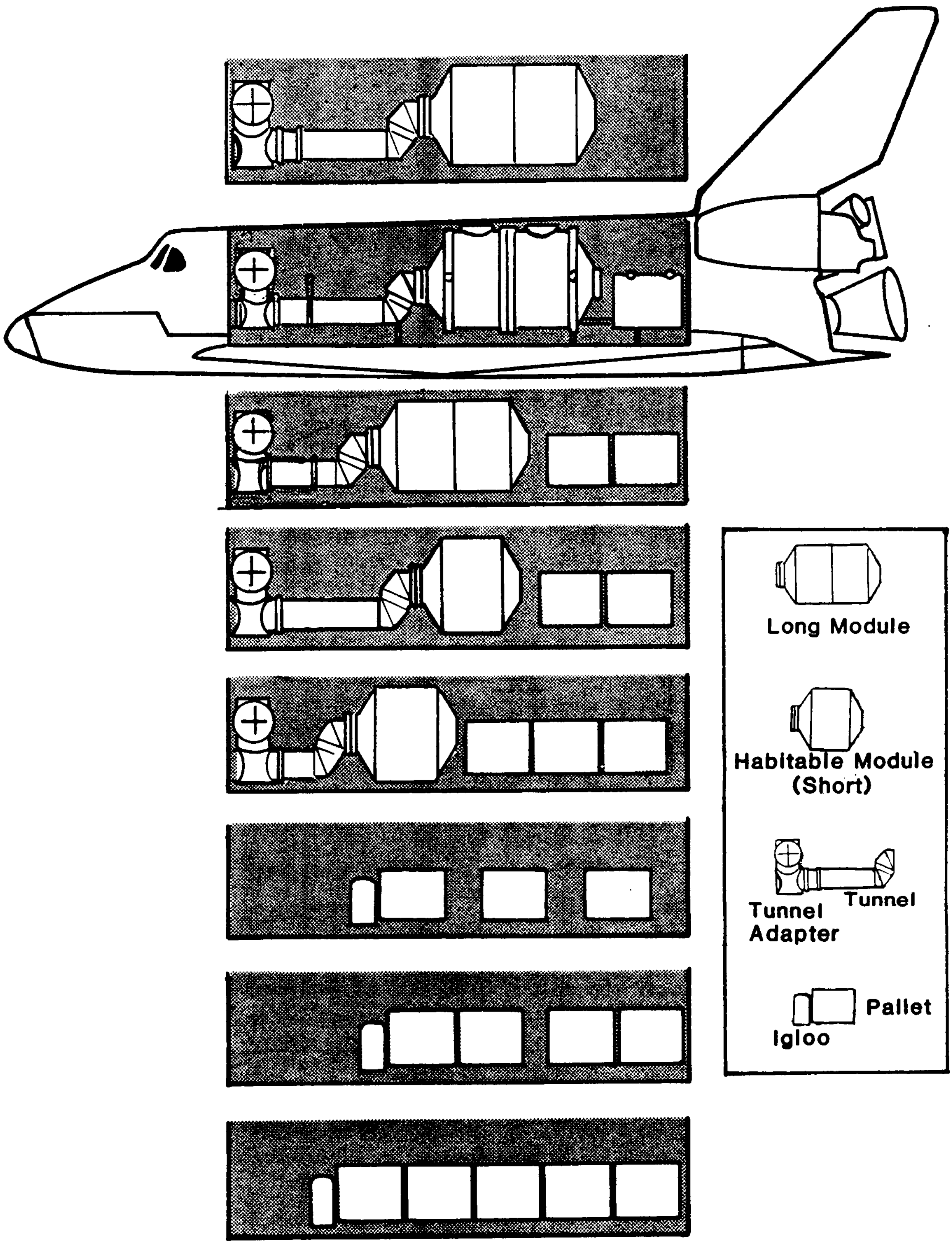


Figure 11-3. Spacelab Modular Configurations

TDRSS, when completed, will be composed of three large state-of-the-art communications satellites measuring 57 feet across and weighing approximately 5,000 pounds each, see Figure 11-4. Each satellite will be placed in a Geosynchronous orbit (22,300 miles). One such satellite is in orbit as of this writing. These orbits will be established geometrically to provide a central ground point, White Sands New Mexico, from which all functions of the system can be controlled. From a geosynchronous orbit, the TDRSS will be able to communicate with more than 85% of the Earth-orbiting satellites. The whole TDRSS mission can be tracked and controlled from one ground location. The data link will flow from the ground station to a Tracking and Data Relay Satellite (TDRS) to the orbiting satellite and back, see Figure 11-5.

The current GSTDN system consists of 15 ground stations and uses some 2,500 personnel on Shuttle missions. Communications and tracking are passed from ground station to ground station as satellites pass in and out of view. All but a few of these GSTDN centers, however, will eventually be replaced by TDRSS.

The Spacelab Data Processing Facility (SLDPF) handles the volumes of data transmitted through the TDRSS. After the data are collected, processed and stored at Goddard Space Flight Center, Greenbelt, Maryland, they are shipped to the users processing center. Some 60 percent of the data collected by Spacelab 1 passed through the SLDPF.

11.4 SPACELAB 1: Materials Science Payload

Thirty Materials Science experiments were conducted on Spacelab 1. The majority of these experiments were performed in hardware located in a double rack, known as the Materials Science Double Rack (MSDR).

The MSDR, shown in Figure 11-6, holds four multiuser facilities:

- Isothermal Heating Facility
- Gradient Heating Facility
- Mirror Heating Facility
- Fluid Physics Module

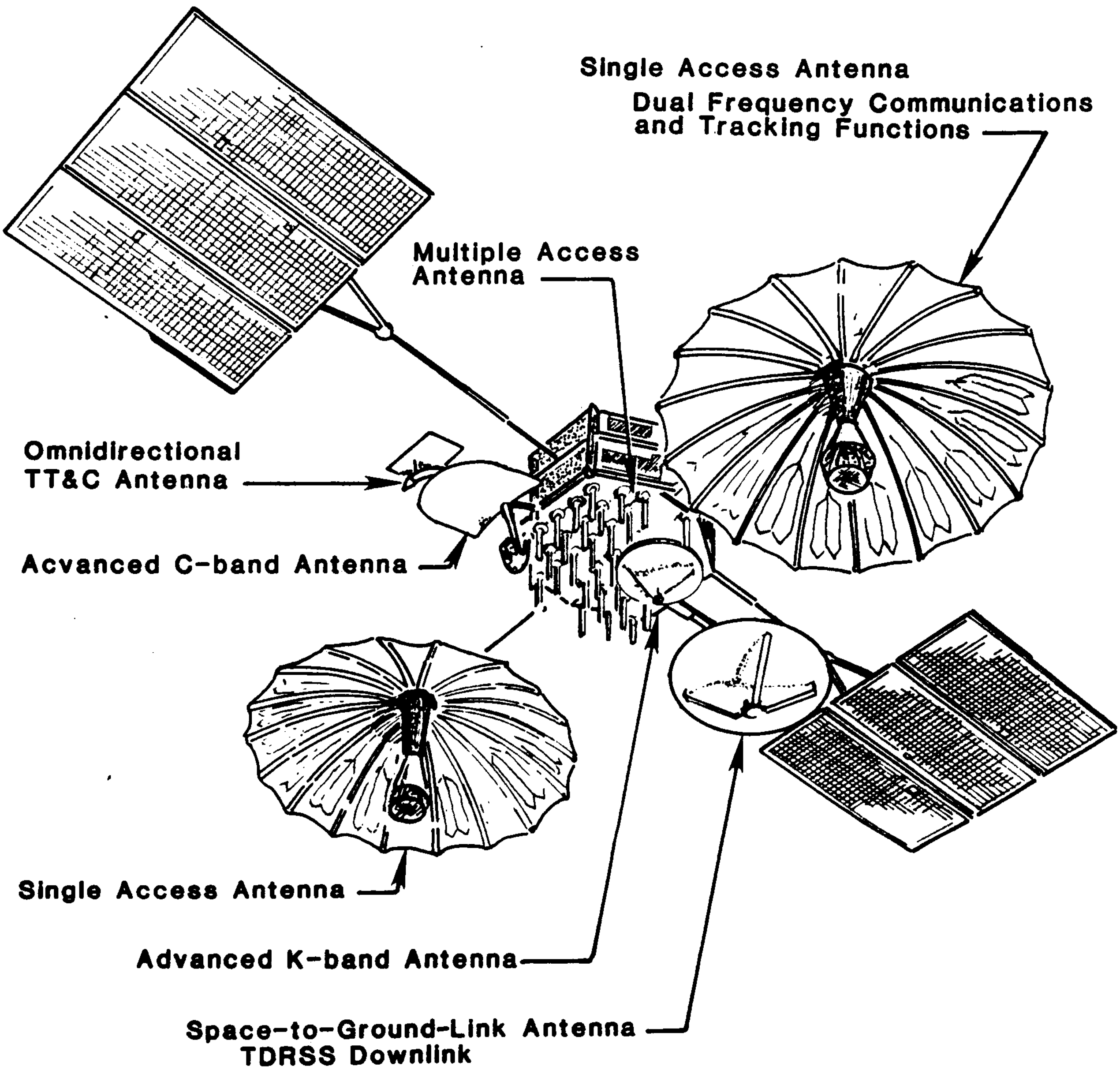


Figure 11-4. Tracking and Data Relay Satellite (TDRS) Antenna Equipment

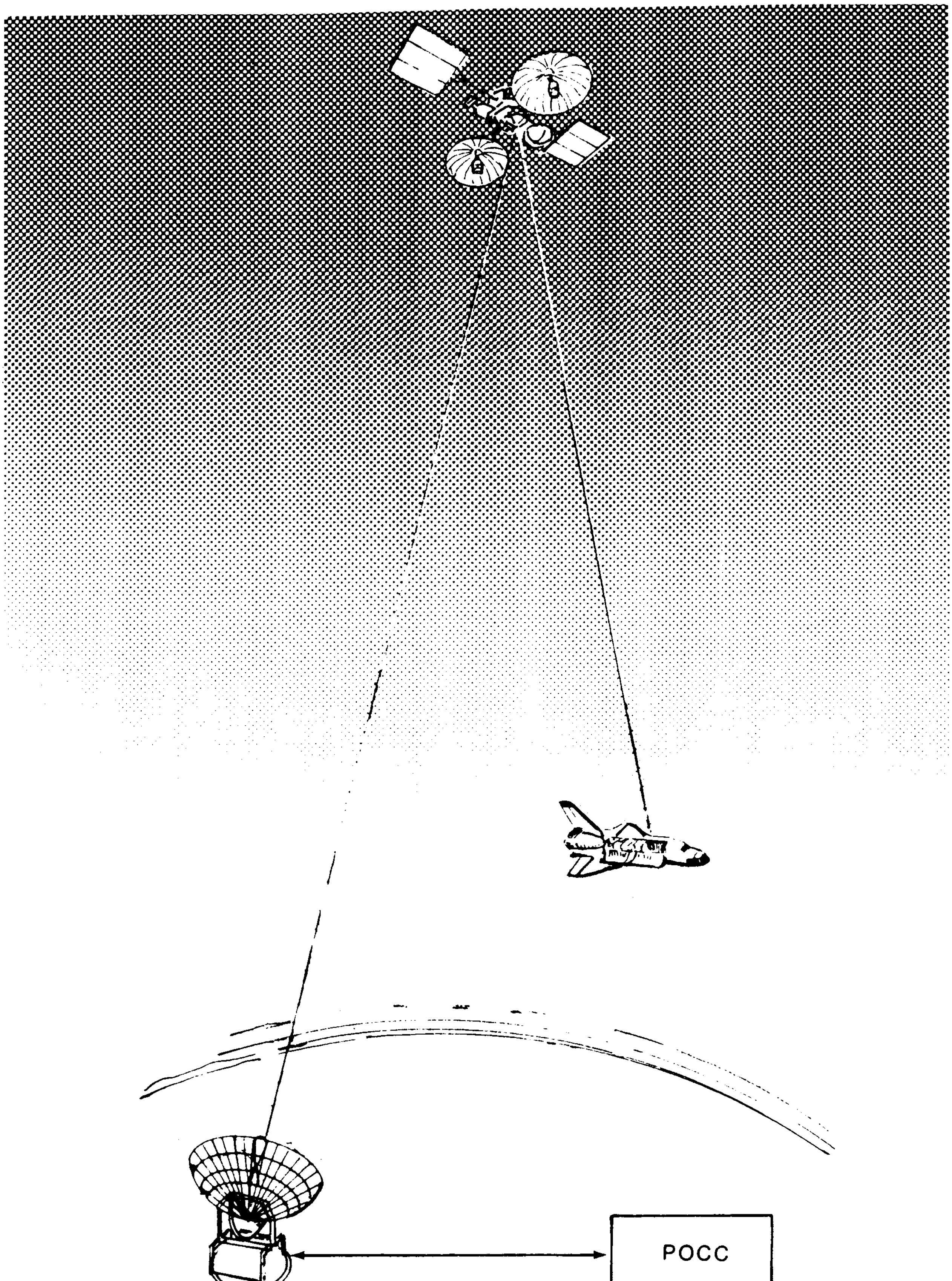


Figure 11-5. Data Link - Communications Between Spacelab and Ground

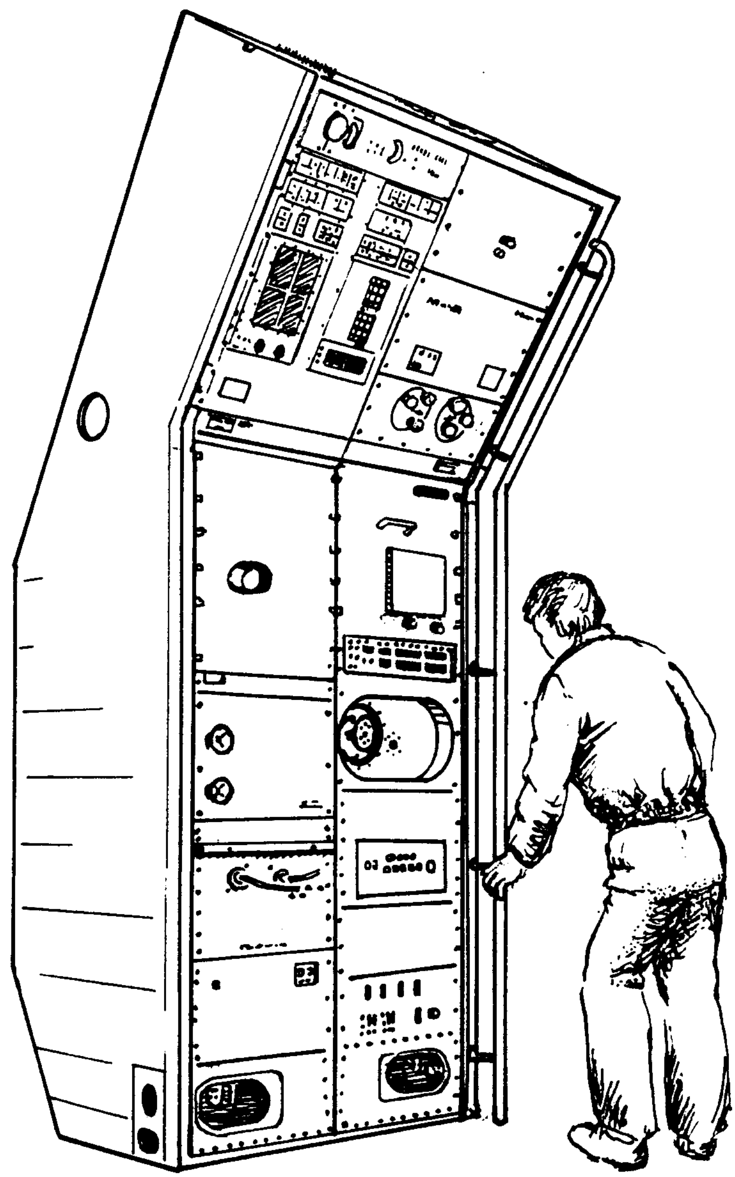


Figure 11-6 Material Science Double Rack (MSDR)

Three special facilities were added to the MSDR:

- Cryostat for protein crystal growth
- High-Temperature Thermostat
- Ultrahigh Vacuum Chamber

In addition, two temperature furnaces, external to the MSDR, were included:

- Low-Temperature Thermostat -
  2 crystal-growth experiments from solutions
- Low-Temperature Heat-Pipe Furnace -
  crystal-growth from vapor experiment

The actual experiments conducted on Spacelab I are listed in Appendix B.

Spacelab I proved to be an effective, and flexible orbiting laboratory. Several in-flight repairs of hardware were required, over 200 replanning requests were referred to Spacelab scientists while in orbit, and approximately 800 operation adjustment requests were completed during the mission. Through the TDRSS communications satellites, scientists were able to work closely with ground personnel, adding a new dimension to space-based research.

XII. UNMANNED MPS SATELLITES

12.0 Discussion

A potentially significant offshoot of the Space Shuttle program is the deployment of unmanned satellites equipped with commercial payloads specifically prepared for microgravity research and development. These "free-flyers" would be transported into space by a Shuttle or by an Expendable Launch Vehicle (ELV), and serviced every six months thereafter. Such unmanned ventures are expected to be cost efficient with high research dividends, due to extended flight time capacity and a greater utilization of microgravity.

Two unmanned satellite programs have been conceived. Fairchild Industries, a U.S. based firm, is developing an unmanned microgravity applications platform which they have named "Leasecraft"; the European Space Agency (ESA) is developing a smaller platform named "EURECA". These unmanned satellites are expected to be in operation by 1987.

12.1 Concept

Free flying satellites would accommodate many non-MPS commercial applications in such areas as remote sensing, astrological studies, etc. This chapter however, will examine their applications to MPS, whose long duration microgravity goals are in keeping with the extended flight capacity of free flying satellites.

A free flyer platform would be Shuttled or delivered by an ELV to space and tended there by either an ESA spacecraft or NASA's Shuttle. Eventually these flights will be run in conjunction with Space Station operations. The platform will provide its own basic power requirements and special maneuvers needed to achieve the desired ideal microgravity effects. Approximately every six months the platform would be retrieved and serviced in flight or returned to Earth by a Shuttle; the payload would then be exchanged and the platform prepared for redeployment.

The advantages of free flying satellite operations are:

- o microgravity durations for up to six months;

- o minimal maneuvering or other activities which cause fluctuation in microgravity (g-jitter);

- o cost effectiveness;

- o operations at higher altitudes than Shuttle flights, further reducing the effects of gravity.

The principal drawbacks to these operations are that even small malfunctions would be costly, repairs would be limited, and immediate servicing would be minimal.

12.2 EURECA

EURECA, shown in Figure 12-1, is an acronym for the European Retrievable Carrier. It is owned and operated by ESA, which will be dependent upon NASA for Shuttle delivery of the carrier into space. During its free flight deployment stage, EURECA will be controlled through the European Space Operations Center in Darmstadt, West Germany.

The core payload for EURECA will be returned to the ground by the Shuttle.

The technical services provided by EURECA's core payload will include:

1) payload mass (total) of 1000 kg

2) 1700 Watts of continuous power

3) heat rejection cooling loop with a throughput of approximately 1000 kg/hr of freon 114. The cooling fluid temperature ranges between +5° and +45°C.

4) total continuous data will be available to the payload at a rate of approximately 2.5 kbps (ESA brochure BR-16 pg. 3).

This payload will be returned to ESA by the Shuttle upon flight completion.

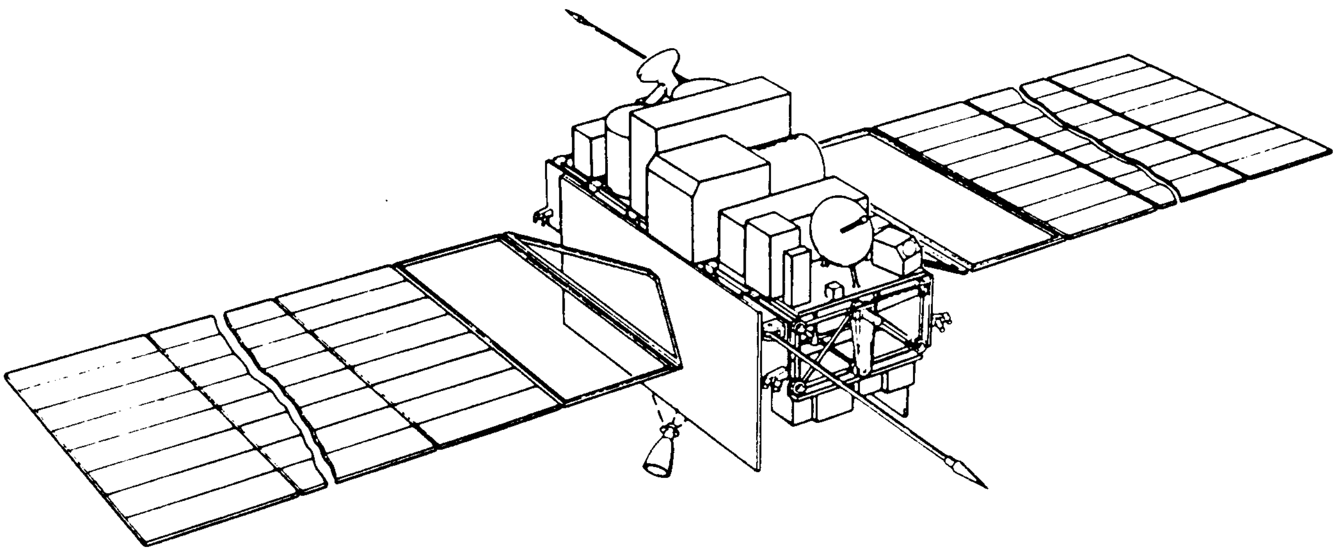


Figure 12-1. European Retrievable Carrier - Eureca

More detailed information on EURECA may be obtained through:

Director of STA - EURECA
ESA
8-10 RUE MARIO NIKIS
F-75738 PARIS, CEDIX 15
FRANCE

12.3 LEASECRAFT

The Leasecraft spacecraft, shown in Figure 12-2, will be larger than EURECA but will function in much the same way. It will be Shuttle delivered and controlled from the ground through a TDRSS communications link. Its key characteristics are:

- o primary payload up to 14,500 kg (32,000 lbs)
- o secondary payloads up to 1,000 kg (2,200 lbs)
- o Operating in low Earth orbit at 28.5 degrees inclination
- o Voltage of 28 $\pm$ 7 VDC
- o Maximum Power 1,000; 2,600; 4,200; 5,700; 7,300 Watts (1-5 power modules)
- o propulsion system for orbit adjustment and special maneuvering.

More detailed information on LEASECRAFT can be obtained by contacting:

Fairchild Space Operations Company
20301 Century Boulevard
Germantown, Maryland 20874-1181
(301) 428-6000

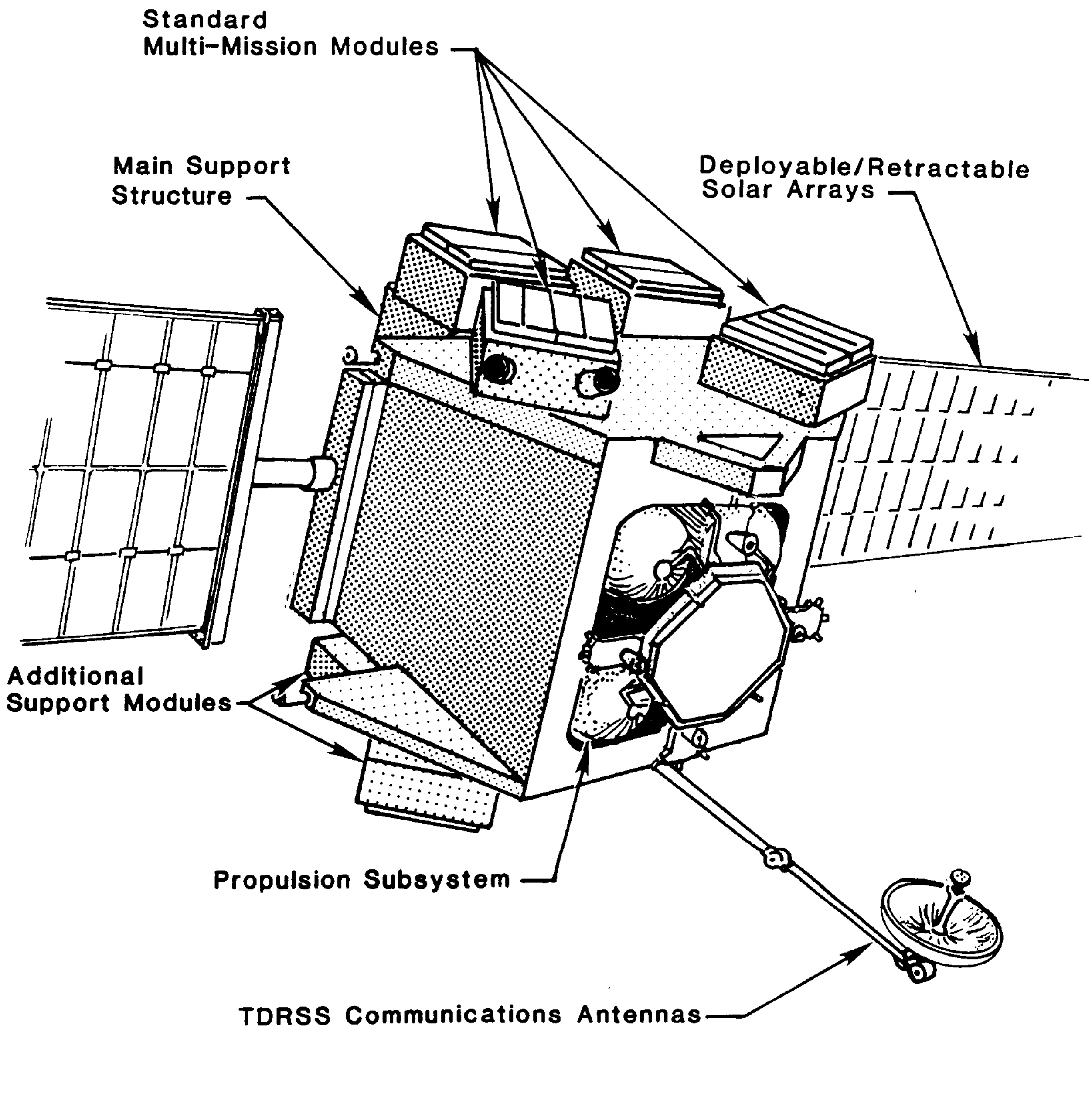


Figure 12-2. Leasecraft

XIII. PRODUCTS WITH COMMERCIAL PROMISE

13.0 Purpose

The purpose of this section is to present products which, from an initial assessment, represent the highest promise for commercial application of MPS.

Products examined in this chapter are derived from two sources:

- o results achieved in microgravity experimentation;
- o applications projections which indicate potentially significant advances in materials properties.

13.1 Criteria for Selection of Candidate Products

Products with MPS commercialization potential are divided into three broad categories:

(1) products which have a high value to weight ratio;

(2) unique products which cannot be processed effectively on earth;

(3) products which can be more effectively processed in space.

13.1.1 High value to weight ratio

Materials processing in space is expensive. Estimates of gross processing cost, including tare, can range from $500,000 to $1,400,000 per kilogram. This estimate includes tare cost, i.e., the cost of transporting processing equipment and the materials storage facilities. An exact processing cost is determined by the specific product and process employed. Figure 13-1 illustrates the estimated gross production costs for a typical product.[1]

Essential criteria for determining candidate products for commercial manufacturing in space is that they should be sufficiently light to minimize transportation charges and sufficiently valuable to insure that their market value offsets the costs attributable to transportation. An example of such products is pharmaceuticals, whose prices range up to billions of dollars per kilogram.

13.1.2 Producing Unique Products

If a product cannot be acceptably processed on Earth but is amenable to space processing, it warrants consideration as a candidate for MPS.

Such unique products could potentially create a new market or prove to be of such superior quality as to produce a high value per weight ratio.

A possible example of a unique product would be large bodies of metallic glasses. Earth-based technology can manufacture only small beads of metallic glasses; demand for large bodies of metallic glasses could become high enough to justify the cost of processing in space.

13.1.3 Producing Materials More Effectively

The value of a product should increase and its cost should decrease as its processing improves. A 400 to 1 improvement in the effectiveness of space processing over terrestrial processing is a realistic threshold for selecting candidate processes for MPS.[2]

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1 "Commercial Materials Processing in Low-g (MPLG): Overview of Commercialization Activities", a briefing by Marshall Space Flight Center, presented at NASA Headquarters on March 7, 1983.

2 ibid. MSFC briefing.

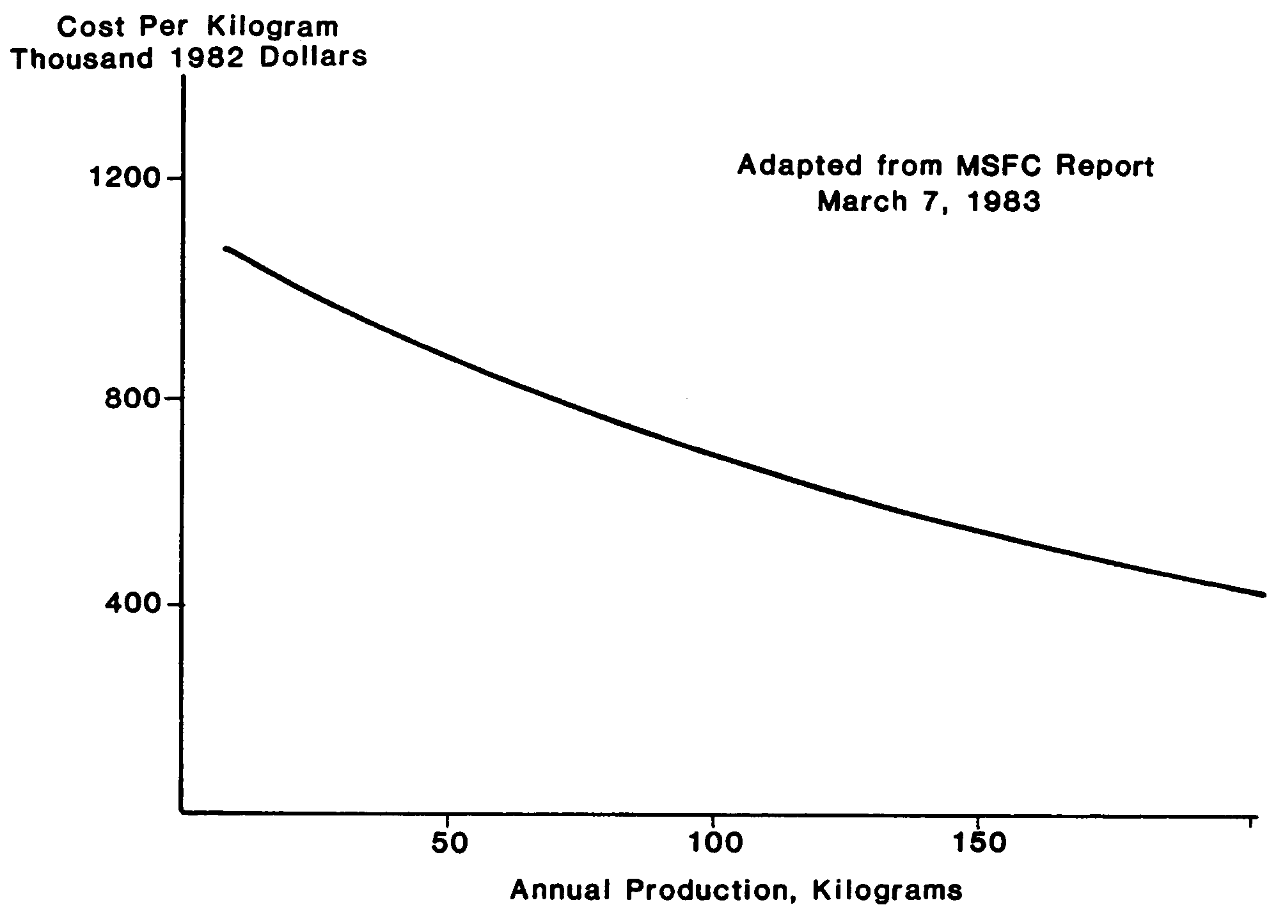

Figure 13-1. Typical Space - Gross Production Costs (Monodispersed Latex Spheres)

13.2 Examples of Products with Commercial Promise

The selection criteria established above -- i.e., high value to weight ratio, production of unique products, potential for process improvement -- can be used to extrapolate commercial applications from selected MPS investigations.

In this section, five examples of products with commercial promise are developed. The first four derive from actual investigations; the final example -- high strength materials -- is based upon theoretical considerations. These examples provide an imaginative yet pragmatic, outlook for future work in this field.

13.2.1 Pharmaceuticals

"Pharmaceuticals" or "drugs" are defined, in their broadest sense, as substances that are used in (1) the diagnosis, treatment, mitigation or prevention of disease, abnormal physical states or symptoms thereof, and (2) the restoration, correction and modification of organic functions.

Major drug groups include:

- Anesthetics - causing a loss of sense perception;
- Antiseptics and Germicides - safeguarding against infection;
- Chemotherapeutic drugs - chemicals used to treat or investigate a variety of diseases such as malaria, and abnormal physical states such as cancer;
- Hormones - glandular excretions affecting growth and other bodily functions;
- Tranquilizers - inducing a calm mental state;
- Vitamins - complex organic substances essential in small amounts to sustain a variety of body functions essential or important to health.

Drugs are classified in the trade in one of three ways:

- o by pharmacological use, i.e., based upon which bodily functions they affect;

- o by therapeutic use, i.e., according to what conditions they can impact or treat; or

- o by chemical group.

Pharmacological and therapeutic classifications do not necessarily account for the physical process by which a drug is produced; chemical classifications are better suited to this end. Thus the following classification is by chemical group.

Pharmaceuticals comprise a large and diverse universe of ethical drugs, biochemicals and immunochemicals.

- o The term ethical drug refers to all drugs of whatever origin whose use conforms to the standards of medical practice. Examples of drugs not considered "ethical" in this country are heroin, LSD and other drugs for which there is no recognized therapeutic use in medicine.

- o Biochemicals, a subject of ethical drugs, are of plant and animal origin (as opposed to mineral), derived from natural products or by means of laboratory synthesis. Biochemicals range in complexity from simple organic buffers to complex metabolic products such as vitamin B_{12}.

- o Immunochemicals are a subset of biochemicals. They include antisera and antigens, which are used to provide immunity to diseases or to control the advance of maladies and abnormal bodily functions.

A breakdown of Biochemical and Immunochemicals into major product profile categories is shown in Figure 13-2. Each of the categories on the bottom tier of the chart represents from tens to hundreds of individual chemical compounds.

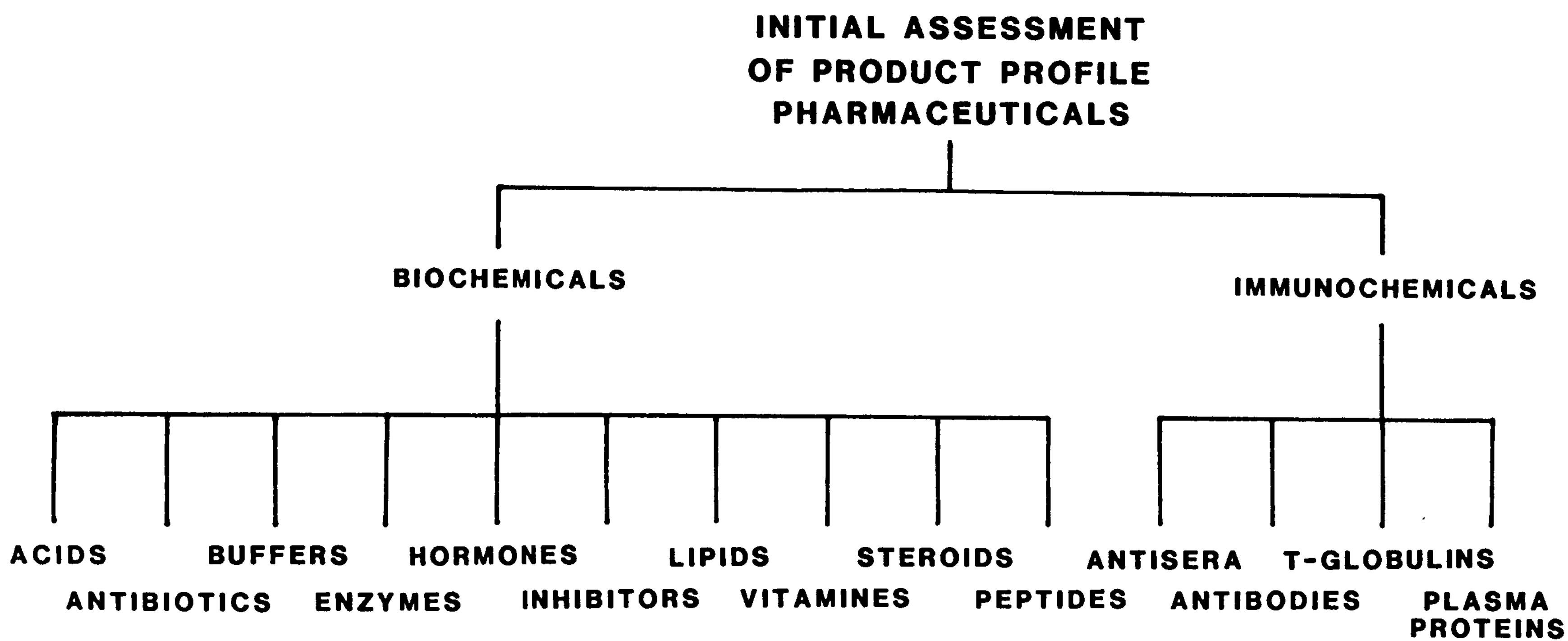

Figure 13-2. Product Profiles of Pharmaceuticles

Drugs constitute the most conspicuous category of materials exhibiting the property of high value to weight ratio. Table 13-1 illustrates a sample of selected pharmaceuticals sold for more than $1,000,000,000 per kilogram. Figure 13-3, constructed from a drug specialty catalog, depicts the relative costs of selected pharmaceuticals as a function of price.

There is a continuing need in the biomedical community to improve separation and purification techniques of living cell components, cell by-products and proteins.

Distinct separation is required because these materials are found in very low concentrations, embedded in matrices of other very similar materials, e.g., beta cells in a mixture of cells comprising a pancreas. The process of collecting these materials in concentrated form is, thus, quite costly.

Purification is needed in cases where the desired target drug, in its natural form, is intermixed with substances which are either potentially harmful, or which produce undesired side-effects.

High priority candidates for separation and purification in the space environment are beta cells, interferon, epidermal growth factor products, growth hormone products, antitrypsin products and antihemophilic products.

Electrophoresis is a processing technique used to separate and purify biological materials in a fluid by the application of an electric charge. McDonnell Douglas estimates that electrophoretic processing in space can enhance throughput by a factor of 500, with up to a five-fold increase in purity over Earth-bound processes. (See Chapter VII for a further discussion of Electrophoresis).

13.2.2 Large Monodispersed Latex Spheres

A polyvinyl latex, grown by the polymerization of a monomer in the presence of a surfactant and water, yields a vast number of microscopic spherical particles that are nearly identical in size. The size distribution is so narrow that the particles have become widely used as calibration standards for electron microscopy. A remarkable number of uses has been found for these monodispersed particles, ranging from seriological tests for a number of diseases to the measurement of spore sizes in biological and other membranes.

TABLE 13-1

SELECTED PHARMACEUTICALS SOLD FOR MORE THAN ONE BILLION DOLLARS PER KILOGRAM

PHARMACEUTICAL	BILLION DOLLARS PER KILOGRAM
Alfatoxin M_1, Asperaillus flavus	$ 5.00
Bathropsinase Reagent	14.50
Cholecystokinin Octapeptide	1.80
Chorionic Gonadotropin, (hCG), Human, Iodination grade	3.20
Chymotrypsin, Human Pancreatic, Iodination grade	3.00
C-Peptide, Human, standard	1.80
C-Peptide, Human, Tyrosylated, Iodination grade	8.00
Deoxyribonucleic Acid, SV40	6.25
Ferritin, Human Spleen, Iodination and standard grade	2.45
α - Feto Protein (AFP), Human, Iodination grade	2.50
α - Feto Protein (AFP), Human	20.00
α - Feto Protein (AFP), Mouse	1.50
Follicle-Stimulating Hormone, (hFSH), Human, Iodination grade	5.60
Growth Hormone, Human (hGH), Iodination grade	2.00
Luteinizing Hormone, Human (hLH). Iodination grade	2.15
Parathyroid Hormone (PTH), Bovine 1-84, Iodination grade	5.00
Prolactin, Human (hPRL), Iodination grade	2.45
Thyroid-Stimulating Hormone, Human, Pituitary (hTSH), Iodination grade	4.00
Thyroid-Stimulating Hormone, Human, α - subunit (hTSH), Iodination grade	5.30
Thyroid Stimulating Hormone, Human, β - subunit (hTSH), Iodination grade	4.36
Trypsin, Human, Pancreas, Iodination grade	3.00
Vinculin, Chicken Gizzard	1.00

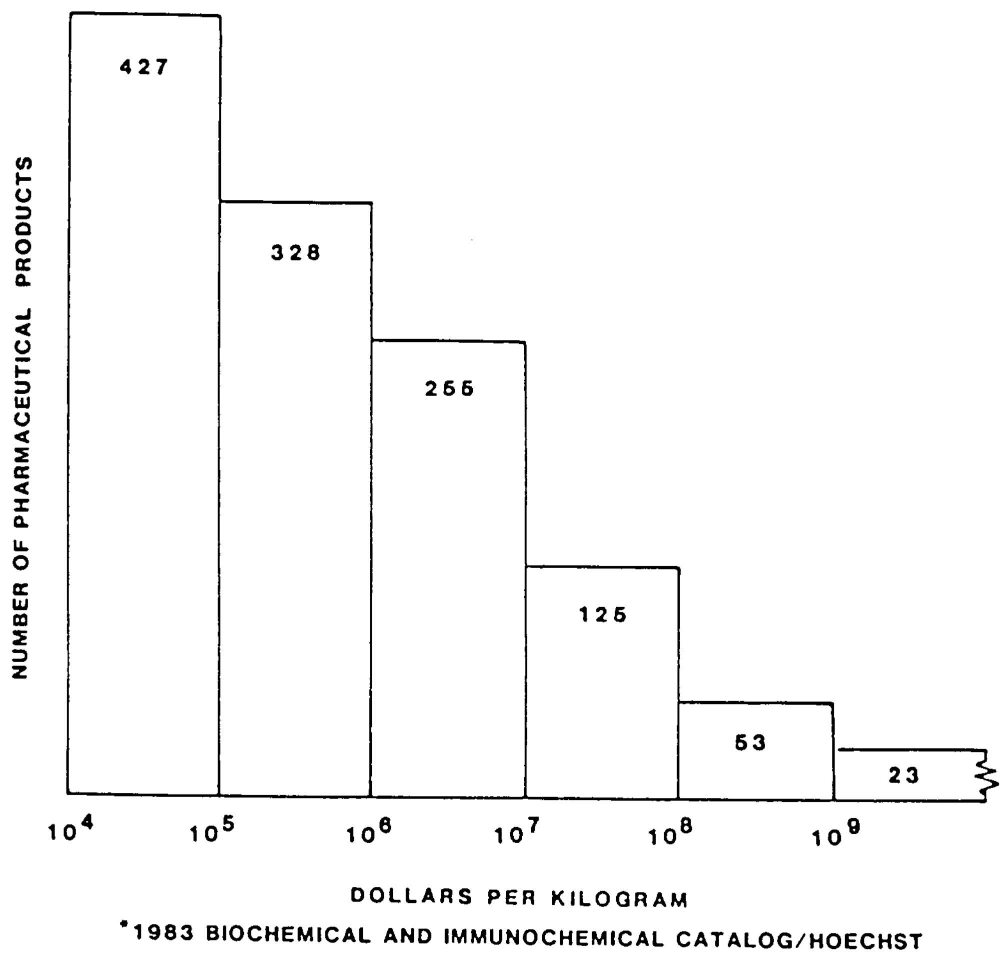

Figure 13-3. Relative Costs of Selected Pharmaceuticles

During a conventional terrestrial growth process, latex spheres are maintained in suspension by intrinsic Brownian motion until their diameter reaches approximately two microns, at which point they tend to sediment under normal one-g gravity. For larger diameters, a sphere's suspension can be further maintained by gentle stirring. However, extreme care must be taken to prevent flocculation or the initiation of a new batch of particles. MPS literature identifies the breakover point as occurring at two microns. Thus monodispersed spheres are not commercially available in large sizes, although MSFC researchers relate that the Dow Chemical Company has placed spheres in the market as large as 10 to 15 millimeters in small quantities.

MSFC developed a unique process to produce spheres up to 40 microns in diameter with characteristics of uniformity of diameters and deviation from roundness considerably superior to those achieved commercially. This MSFC process has been tested on the ground. MSFC researchers have also produced significantly improved characteristics of uniformity of diameter uniformity, roundness, and upper dimensions, by microgravity processing on Shuttle missions.

Ground-produced latex spheres up to 15 microns in diameter are sold currently in one ounce bottles containing 0.1% solid spheres for $65. This equates to $473,000 per kilogram at retail price. It is believed that larger sizes, up to 40 microns, will command a higher price. MSFC estimates that space production costs for latex spheres may range from $900 per gram for 50 kilograms produced to $500 per gram for 200 kilograms produced annually.*

13.2.3 "Ultra-Soft" Magnetic Materials

Transformers, motors, generators, magnetic memories and other devices, which operate with alternating or variable currents and employ materials conventionally designated "ferromagnetic", function less than efficiently in terms of the amount of energy that they lose rather than transform . Losses are caused by heat generated by the effects of hysteresis and eddy currents in the presence of alternating or variable currents. Hysteresis losses are a function of frequency and dominated by the choice of

* Op cit briefing to NASA Headquarters

ferromagnetic materials. Eddy current losses can be controlled to some extent by the geometry of ferromagnetic elements; they are proportional to the square of the frequency of the alternating currents.

In the case of hysteresis the magnetization of ferromagnetic materials (expressed as the flux density, B) "lags" behind the action of the magnetic field (expressed as the magnetic field strength, H). When the magnetic field strength is decreased to zero, the flux density retains some residual value -- termed remanence, residual induction or retentivity.* Conversely, a certain amount of opposite-polarity magnetic field strength is required to cancel out the retentivity; this is known as the coercive force. The integral under the retentivity - coercive force loop is proportional to the hysteresis loss. Hence, the "softer" the magnetic properties of a ferromagnetic material, the smaller the hysteresis loss and correspondingly the greater the energy efficiency of the device.

An important segment of MPS experimentation in ferromagnetic materials is the production of bulk metallic glasses. This experimentation focuses on the feasibility of producing metallic glasses through containerless processes by severe undercooling and the elimination of container-induced nucleation sites.

Currently, metallic glasses may be made on Earth only in very small quantities due to limitations in the technology for rapidly cooling such glasses to the amorphous state, bypassing crystallization. However, the production of small amounts of metallic glass in ground-based research does demonstrate that the Pd-Si-Cu metallic compound exhibits "very soft" magnetic properties.

MPS technology portends the possibility of producing macroscale amounts of metallic glasses from which to fabricate high-grade, high frequency laminations or ferrite-like transformer cores. Although SPAR flight experiments with metallic glasses have failed, thus far, due to equipment failure, future experiments are planned.

* Permanent (so called "hand") magnets characteristically have high remanence while "soft magnets" are ferromagnetic materials with low remanences.

13.2.4 Immiscible Materials

Immiscible materials represent a broad category of multiphase material systems which exhibit a "miscibility gap" in their phase diagram. At a certain level of relative concentration, one component of the system tends to separate from the other component and they are not then able to be remixed. A classic example of immiscible materials is oil and water. As a result of their immiscible components, certain metal alloys cannot be made readily because the metals separate when melted and continue to remain distinct upon cooling.

Several materials whose compounds are immiscible in their fluid phase are of interest for space processing. Examples are:

- o superconductors
- o electrical contact materials
- o III - V semiconductors
- o catalysts
- o permanent magnets
- o bearings and
- o superplastic materials

Nearly 250 liquid phase immiscible materials have been identified as potential superconductors (see Table 13-2).

Skylab experimentation investigated the possibility of preparing immiscible alloys by isothermal and directional solidification. One alloy, 76.85 weight percent gold and 23.15 percent germanium, was selected because of its almost complete solid state immiscibility. As expected, samples solidified in space were signficantly more homogeneous in structure than their counterparts produced on Earth.

These results suggest the value of future, space-based solidification of unique and sufficiently valuable materials, or to indirectly improve Earth-bound technology.

TABLE 13-2

LIQUID PHASE IMMISCIBLE MATERIALS
SUGGESTED FOR SUPERCONDUCTING PROPERTIES

Ag-Cb	B-Bi	Bi-Ru	Cb-Pb	Cr-Sn	Ga-Hg	La-Ta	Mo-Sb	Pu-Ta
Ag-Ir	B-Cd	Bi-Si	Cb-Pu	Cs-Ga	Ga-K	La-Ti	Mo-Sc	Re-Sn
Ag-Mo	B-Ga	Bi-U	Cb-Sc	Cs-In	Ga-Pb	La-U	Mo-Sn	Re-Zn
Ag-Re	B-Hg	Bi-V	Cb-Sn	Cu-Mo	Ga-Te	La-V	Mo-Y	Ru-Zn
Ag-Ru	B-In	Bi-W	Cb-Y	Cu-Os	Ga-Tl	La-Yb	Na-Ta	S-Sn
Ag-Ta	B-Pb	Bi-Zn	Cb-Yb	Cu-Pb	Ga-W	La-Zr	Na-U	S-Tl
Ag-U	B-Sn	C-Cd	Cd-Cr	Cu-Re	Gd-Mo	Li-Mo	Na-Zn	Sc-U
Ag-V	B-Tl	C-Hg	Cd-Fe	Cu-Ru	Gd-Ta	Li-Ta	Na-Zr	Sc-V
Al-As	Be-Bi	C-Pb	Cd-Ga	Cu-Ta	Gd-U	Li-Ti	Nd-Ta	Se-Sn
Al-Bi	Be-Ga	C-Sn	Cd-K	Cu-Tl	Gd-V	Li-U	Nd-Ti	Se-Tl
Al-C	Be-Ge	C-Tl	Cd-Pu	Cu-U	Gd-W	Li-V	Nd-U	Se-Zn
Al-Cd	Be-Hg	C-Zn	Cd-Se	Cu-V	Ge-Hg	Li-Zr	Nd-V	Si-Tl
Al-Cs	Be-In	Ca-Cb	Cd-Si	Dy-Mo	Hg-Sc	Lu-Ta	Ni-Pb	Sm-U
Al-In	Be-Mg	Ca-Cd	Cd-Tc	Dy-Ta	Hg-Si	Lu-U	Os-Sn	Sm-V
Al-K	Be-Pu	Ca-Gd	Ce-Mo	Dy-Ti	Hg-Ta	Lu-V	P-Sn	Sm-W
Al-Na	Be-Sn	Ca-La	Ce-Ta	Dy-U	Hg-V	Mg-Mo	P-Tl	Ta-Tb
Al-Pb	Be-U	Ca-U	Ce-Ti	Dy-V	Hg-W	Mg-Ti	Pb-Pm	Ta-Y
Al-Rb	Bi-C	Cb-Ce	Ce-U	Er-Mo	Ho-U	Mg-U	Pb-Se	Tb-U
Al-S	Bi-Cb	Cb-Cu	Ce-V	Er-Ta	In-S	Mg-V	Pb-Si	Te-Tl
Al-Tl	Bi-Co	Cb-Er	Ce-Zr	Er-Ti	In-Se	Mg-Zr	Pb-U	Th-U
As-Hg	Bi-Cr	Cb-Gd	Co-Hg	Er-U	In-Te	Mn-Pb	Pb-W	Th-Yb
As-Tl	Bi-Pe	Cb-K	Co-Pb	Er-V	K-Mo	Mn-Tl	Pb-Zn	Tl-Zn
Au-Ir	Bi-Ga	Cb-La	Co-Tl	Eu-U	K-Zn	Mo-Nd	Po-Ta	Tm-U
Au-Os	Bi-Ge	Cb-Li	Cr-Gd	Fe-Hg	La-Mn	Mo-Pb	Pr-Ta	U-Y
Au-Re	Bi-Mn	Cb-Mg	Cr-Hg	Fe-Pb	La-Mo	Mo-Po	Pr-Ti	U-Yb
Au-Rh	Bi-Mo	Cb-Na	Cr-Ta	Fe-Sn	La-Pu	Mo-Pr	Pr-U	U-Zn
Au-Ru	Bi-Os	Cb-Nd	Cr-Pb	Fe-Tl	La-Re	Mo-Pu	Pr-V	V-Y
								V-Yb
								W-Zn

13.2.5 High-Strength Materials

The object of this subsection is to exemplify the ultimate potential obtainable in the technology of materials processing. The specific example selected pertains to the stress-strain characteristics of materials.

In a limited number of MPS investigations, microgravity processing has yielded tensile strengths up to 50% greater than obtained under terrestrial gravity. Although these investigations were experimental, with equipment plagued inadequacies, the promise of processing materials with above-normal stress-strain characteristics has clearly emerged.

Table 13-3 shows the tensile strengths of materials commonly used in industry for purposes of civil building, machine construction, and other applications requiring high structural performance. Note that the class of materials, represented in Table 13-3 by boron, and generally included within the broad designation of "ceramics", exhibits tensile strengths which are approximately four to five times those of high-strength steel.

Despite their high tensile strength, these materials are notably brittle, connoting a propensity to crack. When microfractures develop in ceramics they tend to propagate and enlarge, which eventually weakens the pristine material. Thus, structural beams are not fashioned from boron; a few hammer blows would be sufficient to induce cracking, and soon thereafter the beam would fracture.

Modern materials technology has succeeded in exploiting the tensile strength characteristics of ceramic materials by the technique commonly labeled "embedded fiber technology". To illustrate this technology with an example, small-diameter fibers of boron are embedded in a matrix of a softer material--e.g., aluminum, and copper. The boron fibers provide tensile strength and the metal matrix insures protection from cracking.

An even more exciting vista of ultra-strong materials is afforded by the theoretical consideration of the binding forces which underlie the cohesion of matter. As is well known, the principal intermolecular forces in such a structure are of two kinds: the binding-force attraction between charges of opposite electrical polarity, and the strong

TABLE 13-3

TENSILE STRENGTH OF SELECTED MATERIALS

MATERIAL	TENSILE STRENGTH KG/CM^2
IRON FOR CONCRETE REINFORCEMENT	4,000
STRUCTURAL STEEL	10,000
HIGH-STRENGTH STEEL	22,000
DURALUMINUM	4,500
BORON	99,000

quantum repulsion caused by the physical proximity between material particles. The existence of simple material structures is commonly regarded as resulting from the equilibrium of these two opposing forces.

Table 13-4 illustrates the ideal case of a material structure, an intermolecular ionic binding force (ionic crystal), subject to the coulomb attraction between mono-ionic molecules, minus the repulsive force caused by the strong quantum interaction (which varies with an exponential law of their distance). The integration of attractive forces (ions of opposite signs) with repulsive forces (homeopolar ionic charges) is expressed by the "Mabelungen Factor". Note that the ultimate theoretical strength of an ionic material appears to be of order twenty times that of conventionally produced materials.

TABLE 13-4

SUPER-STRENGTH MATERIALS II

INTERMOLECULAR IONIC
BINDING FORCE-IDEAL CASE

$$T = \frac{Q^2 \times 10^{-4}}{4 \pi \epsilon R^4 M}$$

T = IDEAL TENSILE STRENGTH, Kg/CM^2

Q = ELECTRON CHARGE = 1.6×10^{-19} COULOMB

$\mathcal{E}$ = DIELECTRIC CONSTANT = 8.84×10^{-12} FARAD/METER

R = INTERMOLECULAR DISTANCE, METERS

M = MABELUNGEN FACTOR

SOLVE FOR BORON CRYSTAL

T = 2,000,000 KG/CM^2

13.3 Conclusion

In each of the five examples of products with commercial value discussed in this chapter, by-products of known or potential value were identified, as indicated below:

Pharmaceuticals: Beta Cells, Interferon, Epidermal Growth Factor, etc.

Large Monodispersed Latex Spheres: The spheres themselves

Ultra-Soft Magnetic Materials: Ferromagnetic parts for high frequency electronic devices

Immiscible Materials: Superconductors

High Strength Materials: Composites such as SiC/Ag

XIV. CONCLUSIONS

A main objective of this report was to assemble and analyze the results of MPS microgravity experiments conducted onboard the Shuttle Orbiter. The first two Shuttle missions carried no MPS experiments; five experiments were carried on each of the next six successive flights. Shuttle mission 9 carried Spacelab I, which contained 34 materials science experiments.

Figure 14-1 shows the progress of availability access to microgravity for experimentation on MPS Platforms as a function of flight time. Clearly, ten day missions of Skylab I have significantly increase these total microgravity investigation hours.

The planned Leasecraft and Space Station missions will provide platforms to continue these research efforts, augmented with larger, more sophisticated support equipment and prolonged processing time.

A compilation of all Shuttle-based experiment results show the following improved features over pre-Shuttle efforts:

- increased microgravity time to MPS research,
- more power available for MPS research
- a higher priority for MPS among mission objectives
- increased MPS hardware space
- the opportunity for career scientists and engineers to be flown into space and conduct experiments in a class I laboratory environment

The Shuttle has proven to be the most effective platform developed thus far for microgravity research. Hardware and personnel can be efficiently lifted into space on Shuttle flights and returned safely to Earth. Orbitting and other special maneuvers can then be executed to create and sustain microgravity in the order of 10^{-6}g, for several hours. Processing routines can be coordinated and controlled to reduce the g-jitter to

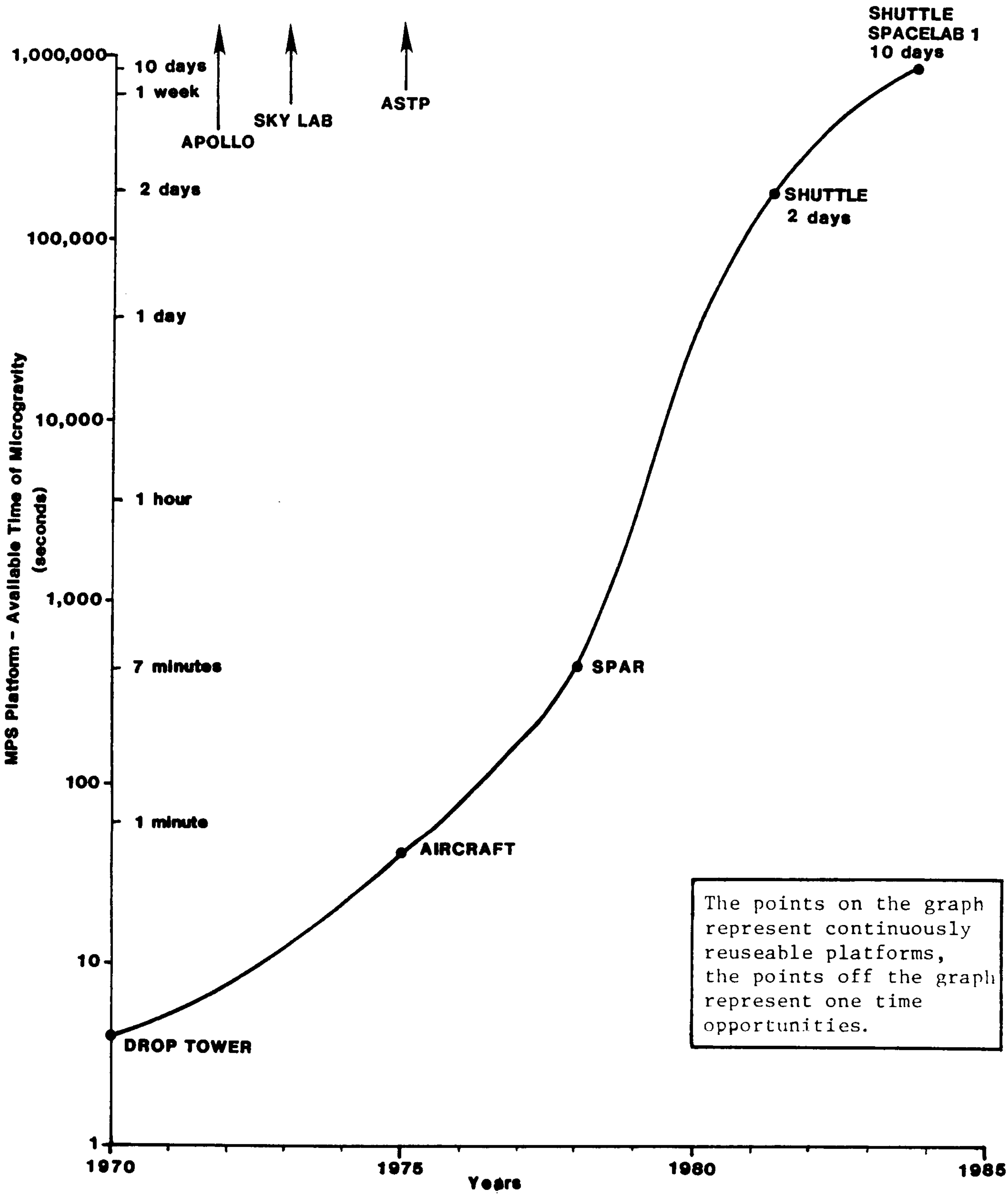

Figure 14-1. MPS Platforms - Progress of Available Access to Microgravity

exceptionally low levels. Experiment programs can be run in a series of highly refined, efficient operations through the cyclic technique of examining and modifying hardware operations between flights.

The advantageous use of the Shuttle operation cycle is demonstrated by the progress of the McDonnell Douglas Continuous Flow Electrophoresis program. A series of Shuttle flight experiments and subsequent ground-based research efforts have refined the techniques, understanding, and hardware to the point where its hardware and throughput have been scaled up to more commercial levels of production. As a result, the Continuous Flow Electrophoresis System will eventually be included on an MPS satellite payload and on the Space Station, which is planned for operation in 1993.

As a platform for research, the Shuttle program has a three fold objective:

- o compile fundamental knowledge,
- o develop useful processes, and
- o screen potential products.

Spacelab, equipped with materials science hardware, is capable of performing the most effective MPS research within the Shuttle flight series. Spacelab opens up a new approach to MPS study,--research conducted first-hand by "Payload Specialists", i.e. career scientists and engineers. Some 2000 hours of microgravity research was conducted on Spacelab 1, more than doubling the total hours of microgravity research prior to Spacelab.

The Shuttle agenda of compiling fundamental knowledge, developing useful processes, and screening potential products sets the stage for the next steps in the commercialization process--the use of free flying MPS satellites and eventually the deployment of the Space Station.

APPENDIX A

SUMMARY OF PRE-SHUTTLE MPS INVESTIGATIONS

This Appendix contains a summarization of MPS-oriented experiments conducted between 1968 and 1980. The information was derived from existing published literature.

The following compilation of pre-shuttle MPS investigations is extracted from ECOsystems International, Inc. Task III final report titled, "User Requirements for the Commercialization of Space", Contract NASW-3674. Task III collected MPS investigations conducted from initial ground studies through the startup of the Space Transportation System (STS) program. Research underway on Task V has updated this data and expanded it to include investigations conducted through the STS 9 flight in December, 1983 (Appendix B). The ultimate objective of this section of the formal report is to identify and capsulize available data on MPS investigation objectives and the Principal Investigator result analysis.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY I

	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
1)	Role of Gravity in Preparative Electrophoresis	Dr. R.S. Snyder MSFC Alabama 35812 Dr. Milan Bier Univ. of Arizona	Skylab	1973	To review the current state-of-the-art in electrophoresis, with particular emphasis on the role of gravity and the use of isotachophoresis, to determine whether microgravity could eliminate convective mixing and achieve protein separations comparable to gel techniques and to determine if larger particles such as cells could be separated by this process.	Separation samples used were human red blood cells and two proteins; ferratin and hemoglobin. The protein separation failed, due to a small amount of air which entered the system and formed around the electrode preventing current flow. The tube with red blood cells produced better results, although the process was affected by electro-osmosis. Results from this Skylab demonstration and the Apollo missions clearly indicate the advantages of a low-g electrophoresis facility. The sharpness and self-restoring properties of boundaries in isotachophoresis make it an attractive candidate for space applications. This is most obvious from the comparison of the sharp boundaries obtained in prior Apollo and ground experiments.
2)	Copper-Aluminum Eutectic	Mr. E.A. Haemeyer MSFC	Skylab	1973	To show that an improved structure of lamellar eutectics could be grown in the absence of gravity induced thermal convection.	Lamellae eutectic specimens processed in zero gravity are superior to ground-base specimens on the basis of two characteristics: the defect spacing in lamellor widths is 12% better and the fault density is 20% less.
3)	Electrophoresis Technology	Dr. R.E.Allen MSCF Dr. G.H.Barlow Abbot Labs	Apollo-Soyuz Test Project	1975	To demonstrate the feasibility of applying free-flow electrophoresis in a static column by using a low-g environment to suppress the convective mixing associated with joule heating.	Enhanced production of orokinase, erythropoietin, and granulocyte conditioning factors were found in the separate cell fractions, which hints that separation according to cell function was accomplished. For example, after kidney cells were fractionated in space, the entire static column was frozen to immobilize the separation and preserve the cells. When the frozen column was sliced on earth, the kidney cells of many fractions proved to have maintained some viability.

CATEGORY I (CONTINUED)

4)	Electrophoresis	Dr. K. Hanning Max Planck Institute for Biochemistry, Munich	Apollo-Soyuz Test Project	1975	To investigate and evaluate the increase in sample flow and sample resolution achievable in space through Electrophoresis.	An improvement in both the resolution and the throughput of continuous flow electrophoresis was demonstrated, albeit with a limited amount of data.
5)	Composite Casting Experiment	I.C. Yates, MSFC	Apollo 14	1971	To investigate the possibility of forming various composite materials with large density differences from the melt.	The space processed samples did not exhibit the separation of phase demonstrated by the ground control samples. While the distribution of the dispersed phase was not as uniform as expected, the paraffin-sodium acetate mixture formed a fairly uniform in situ composite.
6)	Exothermic Brazing	Mr. J.R.Williams Process Engineering Lab. Marshall Space Flight Center Alabama 35812	Skylab	June 12,13 1973	To evaluate brazing as a tube joining technique for the assembly and repair of hardware in space, and to study the spreading, mixing and capillary action of molten braze material in near zero gravity.	Brazing in space was found to be feasible. Molten braze material in zero-gravity environment demonstrated several improvements increased solubility, increased liquid spreading, more uniform monisci (liquid/ vapor interface) and a reduction of braze alloy shrinkage defects.
7)	Metal and Halide Eutectics	Dr. A.S. Yue U.C.L.A. Los Angeles, CA 90024	Skylab	1973	To prepare a fiberlike NaCl-WaF eutectic with continuous VaF fibers embedded in a NaCl matrix and to measure the relevant optical properties of space-grown and earth-grown eutectics.	Continuous NaF fibers were produced in space due to the absence of convection current in the liquid during solidification. Larger transmittance over a wider wavelength was obtained from Skylab grown ingots because of the excellent alignment of NaF fibers embedded in the NACl matrix. Among the three samples grown in Skylab 3, no reaction between the NaCl-NaF eutectic sample and graphic container was detected, and the original shape and length of each sample remained unaffected after resolidification.
8)	Metals Melting	Mr. E.C.Mc Kannan MSFC Alabama, 35812	Skylab	June 1973	To study the behavior of molten metal; to characterize metals melted and environment; and to determine the feasibility of joining metals in space.	It was demonstrated that electron beam welding, cutting and melting can be performed in a low-gravity environment. Specimens solidified in the low-gravity environment of Skylab were characterized by small, equiaxed grains in symmetric subgrain patterns.

CATEGORY I (CONTINUED)

9)	Steady State and Segregation Under Zero Gravity InSb	Prof. A.F. Witt MIT Cambridge, MA 02139	Skylab	1973	To confirm the advantages, pertaining to diffusion and segregation, of a zero gravity environment; to obtain basic data on solidification; and to explore the feasibility of electronic materials processing in outer space.	Ideal diffusion controlled steady state conditions, never achieved on earth, were realized during the growth of Te-doped InSb crystals in Skylab. Surface tension effects established non-wetting conditions under which free surface solidification took place in confined geometry. Under forced contract conditions, surface tension effects led to the formation of surface ridges (not previously observed on earth) which isolated the growth system from its container. In addition, it was possible for the first time to identify unambiguously: the origin of segregation discontinuities associated with facet growth, the mode of nucleation and propagation of rotational twin boundaries, and the specific effect of mechanical-shock perturbations on segregation. These results prove the superior potential of outer space to effect solidification in the absence of gravity induced interference.
10)	Preparation of Silicon Carbide Whisker Reinforced Silver Composite Material in a Weightless Environment	Tomoyoski Kawada National Research Institute for Metals 2-3-12, Nakameguro Meguro-ku, Tokyo, Japan	Skylab	1973	To obtain Ag and SiC whisker composites with high density and uniform distribution of whiskers by heating and pressurizing sintered products above the melting point of Ag in a weightless environment.	By virtue of their uniform hardness distribution and lack of floating whiskers, Skylab samples differed from the ground-based test samples.
11)	Vapor Growth of IV-VI Compounds	Prof. Wiedemeier Rensselaer Polytechnic Inst. Troy, New York 12181 c/o Dept. of Chemistry	Skylab	1973	To establish the positive effects of micro-gravity on crystal growth; to determine the fundamental properties of vapor transport experiments.	This analysis, performed to confirm the unique conditions of weightlessness for materials processing and for the observation of basic transport phenomena is based on a direct comparison of GeSe and Ge Te crystals and of mass transport rates obtained in Earth and in space. The analysis is based on a comparison of deposition patterns, growth habits, optical and scanning electron microscopy of as-grown and cleaved crystal faces, and thermal etching. The results demonstrate unambiguously the superiority of the space crystals in terms of surface perfection, crystalline homogeneity and defect density. Greater vapor transport rates than expected in a microgravity environment suggests the incompleteness of conventional transport models and the improved quality of crystals that can be grown at reasonable rates by this technique in space. These space based results may be utilized to modify crystal growth on earth as well.

CATEGORY I (CONTINUED)

12)	Seeded, Containerless Solidification of Indium Antimonide	Dr. J.U. Walter University of Alabama in Huntsville Sponsor: NASA	Skylab	June 1973	To investigate the feasibility of and obtain information on the space potential for the production and processing of single crystals.	The feasibility of seeded containerless growth was demonstrated. The extremely flat surface facets which were formed in these experiments imply the absence of convectively induced perturbations.
13)	Monotectic and Sytectic Alloys	Dr. L.L. Lacy, MSCF Dr. C.Y. Ang, The Aerospace Corporation	Apollo-Soyuz Test Project	1975	To minimize buoyancy and convective influences in a low-g environment. In normal gravity these influences prevent adequate synthesis of material systems in which significant specific gravity differences exist.	The liquid-state homogenization of polyary stalline, multiphase A/sb in low-g produces major improvements in macroscopic and microscopic homogeneity, showing 4 to 20 times less of the unwanted secondary phase than in l-g.
14)	Crystal Growth (MA 028)	Dr. M.D. Lind Rockwell International Science Center	Apollo-Soyuz Test Project	1975	To investigate the growth of single crystals of insoluble substances by a process in which reactant solutions are allowed to diffuse toward each other through a region of pure solvent.	Precise temperature control was not available, therefore, the materials chosen were calcium tartrate, calcium carbonate, and lead sulfide which can be grown without precise temperature control. Some single crystals produced in low-g were longer than gel-produced in l-g, some were rhombohedral in shape. Birefringence was also exhibited by the low-g grown crystal of calcite. Since the reaction which produced these crystals did not reach completion, the investigator suggested that a longer reaction time or a higher temperature to increase the solubility of the reactants may result in larger crystals. The feasibility of the inter-diffusion of two chemicals in space to form a precipitate product, such as calcium tartrate crystals was demonstrated.
15)	Halide Eutectic Growth	Dr. A. S. Yue et. al. UCLA	Apollo-Soyuz Test Project	1975	To study the growth of LiF fibers.	LiF fiber length in portions of the low-g samples showed a many-fold improvement over LiF l-g fibers. Transmittance of the low-g fibers was reported to exceed that of the l-g fibers by several fold over most of the wavelength band 4 to 10 μm because of the more regular alinement of LiF fibers embedded in the N_aCl matrix. Generally, fibers grown in space are alined more regularly and are more parallel to the growth direction than those grown on Earth. As a result of their more regular fiber alinements, light can transmit farther through the space-grown samples than through those grown on Earth.

CATEGORY I (CONTINUED)

16)	Interface Marking in Crystals	Prof. H.C. Gatos A.F. Witt M. Lichtensteiger C.J. Herman, MIT	Apollo-Soyuz Test Project	1975	To determine the crystal growth rate during the solidification process by utilizing a novel electric pulsing system to mark the interface; to determine dopant segregation, investigate possible non-gravitational convection phenomena, and compare wetting phenomena between l-g and low-g.	In the postflight analysis, the investigators note that the Ge crystal slipped easily from the quartz tube, indicating that wetting did not occur in low-g, as opposed to l-g. This wetting inversion in space-grown crystals may drastically reduce contamination of the melt by their confinement materials. The growth rates of the low-g and l-g crystals were virtually identical, assuming a value of about 9.5 um/sec after about 2.5 cm of growth. Development of a modified segregation theory, which considers the existence of initial growth rate transients, has been initiated on the basis of the data obtained from this experiment. Dopant concentration increases steadily over about 1.5 cm from the regrowth interface but does not reach the anticipated steady-state prediction. While this behavior is not fully understood, it appears that asymmetrical thermal gradients arising from the three furnaces in the module are most likely responsible for the variations in growth rate and dopant distribution. From an analysis of the dopant segregation and compositional homogeneity of the samples, the investigators insist that no time-dependent convective flows occurred in the Ge melts despite the little or no contact between the melt and the container. This feature illustrates the importance of establishing a thermal configuation, producing planar or near-planar solidification fronts to achieve radial compositional homogeneity during crystal growth under diffusion-controlled, near zero-g conditions.
17)	Fluid Dynamics and Thermodynamics of Vapor Phase Crystal Growth	Dr. Herbert Wiedemeier Rensselaer Polytechnic Institute		Jan. 1980 To Dec. 1982	To provide basic mass transport and crystal growth data which, combined with a thorough knowledge of the thermodynamics, will improve the fluid dynamic characterization of vapor transport systems.	The crystals showed improved growth habits surface features and lower defect density than those grown in a similar processor in a terrestrial environment. Dopant concentrations determined in space, influenced by diffusion-controlled processes, demonstrate more uniform growth in the absence of gravity-driven convection. Chemical vapor transport crystal growth rates proved to be substantially higher than expected from extrapolation of laboratory data.

18)	Kidney Cell Electrophoresis	Dr. Paul Todd Penn State Univ.	Ground	June 1980 Cont.	To repeat the MA-011 experiment under conditions which are optimum for the viability of human kidney cells and most favorable for the least possible electrophoretic separation of the few cells (about 5%) which produce urokinase or human granulocyte conditioning factor (HGCF), and erythropocintin.	Cells from cultures obtained from 26 commercially-prepared explants have been studied with respect to electrophoretic mobility distribution, growth in culture, and urokinase production. The testing of various electrophoresis buffers indicates that the low ionic strength required for effective electrophoresis experimentation in microgravity would compromise cell viability. Procedures have been established for urokinase assay of cultures derived from cells separated in microgravity experiments. This analysis will take place on the Shuttle OFT-3 Mission.
19)	Electrophoresis Demonstration	Dr. R.S. Snyder MSFC	Apollo 14 Apollo 17	1971 to 1972	To test the concept of using low-g to prevent unwanted convective flows from Joule heating in static-column, free-flow electrophoresis; and, to identify other possible problem areas associated with electrophoresis, such as bubble formations and non-gravity driven flows.	Sample bands were severely distorted by electroosmotic flows in both experiments; however, these experiments provided the impetus to develop special coatings to lower the zeta potential and eliminate such flows in future experiments.
20)	Sphere Forming	Dr. D.J. Larson Grumman Aerospace Bethpage, New York 11714	Skylab	1973	To study the effects of weightlessness on solidification processes.	Initial and terminal solute redistribution processes were substantially improved in a reduced gravity environment. In this environment microscopic phenomena are typically magnified produce a macroscopic effect.

21)	Crystal Growth from the Vapor Phase	Dr. H. Wiedemeier et.al. Rensselaer Polytechnic Institute	Apollo-Soyuz Test Project	1975	To study the growth of semiconductor crystals by chemical transport reactions using a vapor transport agent in a low-g environment.	No difference was found in the lattice parameters and the orientation of the native growth faces of the crystals formed in low-g and 1-g. However, the turbulent flow characteristic of 1-g growth did not exist in the low-g environment. The low-g grown crystals have smoother surfaces and better defined edges. An average density of etch pits for the space-grown crystals was reported to be one or two orders of magnitude less than the crystals grown in 1-g. As was evidenced in the earlier M-556 experiment, the improvements noted in the structural and chemical homogeneity of the low-g grown crystals are attributable to the reduced convective turbulence and interference with the transport process. In addition to the confirmation of greater mass transport rates in low-g than was predicted, flux results in low-g indicate the existence of thermochemically induced convection in reactive solid-gas phase systems. This thermochemical convection may be over-shadowed by gravity-driven convection in 1-g.
22)	Zero-G Processing of Magnets	Dr. D.J. Larson Grumman Aerospace Corporation	Apollo-Soyuz Test Project	1975	To investigate the effects of the reduction of gravitationally dependent elemental segregation and convection in the soldification of high-coercive-strength magnetic composites in low-g.	The array of MnBi crystals processed isothermally resulted apparently from edge-to-center gradients and produced no unusual magnetic effects. The directionally solidified flight samples showed a considerably different microstructure from the ground control samples. The Mn Bi rods were smaller in diameter in the space environment and were circular in cross section rather than chevron-like. Finally, the coercive strength of the lattice parameter improved by approximately 60 percent in low-g.

CATEGORY I (CONTINUED)

23)	Multiple Materials Melting (metals)	L.I. Ivanov,et.al. Institute for Metallurgy USSR	Apollo-Soyuz	1975	To utilize the low-g environment to reduce gravity-driven segregation effects in the synthesis of compound materials of significantly different specific gravity; to investigate the mutual diffusion and formation of intermetallic phases as a result of the interaction of a meltable matrix (Al) and hard, refractory inclusions (W).	The kinetics of diffusion and phase formation in the solid W (WRe alloy) liquid A l diffusion area were approximately the same for both ground base and flight samples. This conclusion was suggested by the similarity in geometrical characteristics of the the diffusion layer constituents which were observed. The low-g diffusion and phase formation processes for the W-Al, however, were reported to exhibit several differences from the W-Al-Re system. In the binary system, the WAl_5 phases are thinner than in l-g, are needle-shaped, and have a lower distortion angle; the WAl_{12} phase has a crystalline faceting. In the case of the tertiary system, the distinguishing features were reported to include a higher porosity at the diffusion layer/WRe alloy interface, and the formation of phases rich in Al. The CuAl eutectics and powdered Al low-g samples showed no appreciable difference from their Earth-processed counterparts. Melting of the powdered Al suggested that a slight excess of temperature above the Al melting point reduces the possibility of individual particles being fused together in a low-gravity orbital environment.
24)	The Upgrading of Glass Microballoons	Dr. Stanley A. Dunn Bjolksten Research Labs	Ground	August 1978 To August 1982	To study extensively the processes and mechanisms involved in producing glass microballoons of acceptable quality for laser fusion by gas jet levitation and manipulation in the molten condition.	An important technique was developed for producing CHSs of virtually any degree of fineness and aspect ratio (hole length to effective hole diameter). Whereas optimum levitating stability requires larger aspect ratios of the order of 10 and above, most small hole drilling techniques are limited to values of 3 or 2 below. The essence of the subject technique rests upon the discovery that holes of noncircular cross sections may perform quite as satisfactorily as circular. The CHS by this technique consists of a symmetrically packed and confined bundle of uniformly sized wires.

CATEGORY I (CONTINUED)

25)	HgI_2 Crystal Growth for Nuclear Detectors	W.F. Schnepple Dr. L. Vandenberg EG&G Inc. Santa Barbara, CA.	Ground	April 1978 To April 1983	To obtain a benchmark quality sample grown at low-g conditions and to study vapor growth phenomena under space conditions.	Ground-based crystals show a defect structure which impairs their performance as nuclear radiation detectors. These defects may be caused by the gravitational force acting on the crystal in its weakened state at the elevated growth temperature and by irregular convection patterns in the vapor during growth. Mechanical strength measurements were performed (uniaxial compression tests) which show that the crystals exhibit slip parallel to the c-planes at stresses as low as 1/2 psi. Preliminary calculations using a simple linearized model indicate the oscillating instabilities in the convection part of the vapor transport system are unlikely, even at 1 g, provided that the utmost care is taken in the preparation of the crystal growth source material.
26)	Directional Solidification of Magnetic Composites	Dr. R.G.Pirich Grumman Aerospace Corporation	Ground	Feb. 1977 to Feb. 1983	To investigate the finer microstructure and enhanced magnetic properties of Mn-Bi eutectic directionally solidified in space.	Morphological analyses of eutectic Bi/Mnbi samples that were directionally solidified during the 240-s low-g interval of the SPAR VI flight experiment show statistically smaller interrod spacings and rod diameters when compared to samples grown under identical solidification furnace conditions, in the same apparatus, in 1-g. The magnetic property measurements indicate that the flight samples contain ~7 v/o less dispersed MnBi than similarly processed 1-g samples for the same starting composition. Convectively driven temperature fluatuations in the melt, which result in unsteady liquid-solid interface movement in 1-g, are suggested to explain the morphological change between low-g and 1-g solidification. As a result of these fluctuations, an adjustment among the interrod spacing, growth velocity, and total undercooling at the solidification interface is proposed to account for the observed change in volume fraction of dispersed MnBi. Future low-g experiments involving both eutectic (SPAR IX) and off-eutectic (SPAR X) compositions are planned to quantify these unusual low-g effects.

CATEGORY I (CONTINUED)

27)	Germanium Silicon Solid Solutions	U.S. Zemskov et. al. Institute for Metallurgy USSR	Apollo Soyuz	1975	To study the possibility of using micro-gravity conditions for obtaining solid solution monocrystals with uniformly distributed components.	The crystallization in low-g did not occur under the expected ideal stationary growth and segregation conditions because all flight samples melted completely. Convective mining was negligible in the low-g and graphite ampoule walls were not wet by the molten samples.
28)	Preparative Electrophoresis of Living Lymphocytes	Dr. C.J. van Oss State Univ. of NY Buffalo 14214	Skylab	1973	To develop the methodology for electrophoretic cell separation in space by first working out a methodology at gravity=1.	Samples that contain 1-2 X 10^6 human lymphoeytes were separated into T-cell rich factions containing up to 96% T-cells after 1 hour of electrophoresis, as judged by immunofluorescence. Distinct bands of cells were not distinguishable at the conclusion of the electrophoresis. The slowest fractions were enriched 57% in B-cell content (which is not sufficient to use this method to yield purified B cell fractions). Both descending and ascending electrophoretic lymphocyte separation at gravity=1 show the possibilities of as well as the probable limits to lymphocyte electrophoresis on earth. The methodology developed will be applicable, by a simple extrapolation, to a gravity = 0 environment.
29)	Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M Univer. Dr. R. L. Kroes MSFC	Possible Space Lab 3	June 1978 To June 1983	1) To grow TGS crystals from aqueous solution in low-gravity 2) to investigate mass transport and heat flow in a diffusion-controlled growth system, and 3) to evaluate the feasible advantages and technical potential of producing solution growth crystals in space.	Single crystals of TGS were grown using a conventional low temperature solution growth method and the growth process was extensively characterized. Also, a unique technique of growing solution growth crystals by extracting heat at a programmed rate from the crystal through a semi-insulating sting was developed. TGS crystals will be grown by this technique during the Spacelab 3 Mission. Data on heat and mass transport in a diffusion-controlled system will be obtained using a laser holography technique. Analytical studies are underway to estimate growth rates in low-g conditions.

CATEGORY I (CONTINUED)

30)	HgI_2 Crystal Growth for Nuclear Detectors	W. F. Schnepple Dr. L. Vandenberg EG&G, Inc.	Ground	April 1978 To April 1983	Ground-based crystals show a defect structure which impairs their performance as nuclear radiation detectors. These defects may be caused by the gravitational force acting on the crystal in its weakened state at the elevated growth temperature and by irregular convection patterns in the vapor during growth. The objectives of this program are to obtain a benchmark quality sample grown at low-g conditions and to study vapor growth phenomena under the same conditions.	Mechanical strength measurements (uniaxial compression tests) show that the crystals exhibit slip parallels to the c-planes at stresses as low as 10 psi. Preliminary calculations using a simple linearized model indicate the oscillating instabilities in the convection part of the vapor transport system are unlikely, even at 1-g, provided that the utmost care is taken in preparation of the crystal growth source material.
31)	Homogeneous Crystallization Studies of Glass Forming Systems	Dr. E.C. Ethridge Dr. P. Curreri Marshall Space Flight Center	Ground	April 1981 To April 1984	To use containerless as well as pseudo-containerless processing techniques to melt and resolidify borderline glass formers in such a way as to obtain critical cooling rates to avoid homogeneous crystallization	Samples are to be melted and resolidified by containerless and pseudocontainerless means. Critical cooling rates and crystallization rates will be measured.
32)	Acoustic Chamber Processing	Dr. T.G. Wang Jet Propulsion Laboratory	Skylab	1974	To describe an acoustical method that can control any molten material within a container in a space environment.	By readily levitating, positioning, and manipulating materials placed in it, the acoustical resonator can serve a variety of space processing operations, such as drawing crystals, degassing and stirring of melts and castings.

SUMMARY OF MPS INVESTIGATIONS
CATEGORY 2

	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
33)	Heat Flow and Segregation in Directional	Prof. Witt MIT	Ground		To optimize crystal growth and segregation during solidification in Bridgman-type configurations.	Making use of interface demarcation and spreading resistance analyses, it was found that both the growth and segregation of conventional thermal geometries, at constant ampoule lowering rates, remain non-steady state for growth lengths of up to 6 cm. The rate of growth is significantly less than the lowering rate under high thermal gradient conditions but exceeds the lowering rate by a factor of two at low applied thermal gradients. Upon temporary arrest of ampule lowering, uncontrolled growth or back melting takes place, depending on the magnitude of the existing axial thermal gradient. the experimental evidence obtained suggests that conventional vertical Bridgman configurations cannot provide a thermal environment in which steady state crystal growth and radially uniform dopant segregation are achievable. To arrive at an improved Bridgman-type configuration suitable for growth on earth and is a reduced gravity environment, it was decided to base the system design on one-and two-dimensional heat transfer analyses. These calculations suggested the use of aligned heat pipes separated by a gradient zone region with variable heat transfer characteristics. Such a system, the thermal and growth rates of which are currently being characterized, has now been constructed. With the establishment of thermally stabilized growth conditions in a vertical Bridgman configuration, it became possible to study dopant segregation at solidification rates ranging from 0.5 to 15 m/s. This study revealed that the basis for all generally accepted segregation theories, at constant and rate dependent interface distribution coefficient which is identical with the equilibrium distribution coefficient, does not apply to the system germanium-gallium. It was found that during both faceted and nonfaceted growth the interface distribution coefficient differs from k_o and, in the growth range from 0-2 m/s, exhibits a pronounced rate dependence. This finding is of fundamental importance to space processing since this particular system has been and is extensively used for the characterization of growth in a reduced gravity environment.

34)	Convection in Grain Refining	Prof. J. Szekoly Prof. M.C. Flemings MIT	Ground	I	To obtain a better understanding of the relationship among fluid flow phenomena, nucleation, and grain refinement in solidifying metals both in the presence and in the absence of a gravitational field. An ultimate technical aim is to determine ways to achieve significant grain size reductions in hard-to-process melts and significant property refinement by obtaining solidification under highly non equilibrium conditions.	The following is a brief summary of results obtained to date: (1) nickel base alloys samples of approximately 1 gram have been successfully levitated, in inert atmospheres undercooled by amounts up to 270°C, and a wide range of grain sizes and solidification structures obtained, depending on the amount of undercooling and cooling rate; (2) two important innovative techniques have been developed to obtain large amounts of undercooling in high temperature (iron, nickel, and cobalt) alloys. In one of these, the metal is melted and then "emulsified" (stirred into fine droplets) in a finely crushed oxide or salt. In the second, small pre-alloyed metal droplets are interspersed at room temperature with finely crushed oxide or salt. The admixture is then melted; (3) extremely large undercoolings have been obtained through the above two methods because of the fine particle size and cleansing action of the slag; (4) emphasis of the experimental work at the present time is on increasing amounts of undercooling obtainable, and therefore the types of structures obtainable through (a) use of alternative emulsification media, (b) increasing rate of heat extraction, and (c) process variations; (5) a computational capability has been developed to determine the electromagnetic force field, the fluid flow field and the temperature field in induction stirred systems, including contained cylindrical metals and levitated spherical melts; (6) calculations were carried out for a variety of conditions, including heat and fluid flow in a metal held in an inductively stirred cylindrical crucible and levitation melted specimens both on the ground and in a zero gravity environment; (7) calculations have shown that the fluid flow field is markedly different for ground based and for zero-gravity conditions; and, (8) the techniques developed for solving MHD type problems in molten metal and glass systems and the results generated are thought to have made an important contribution to this overall field. The foregoing results of this research have implications both for study of convection at zero-g and for potential engineering application, both at 1-g and at zero-g. As noted before, enormous undercoolings have been obtained at 1-g and greater undercoolings were anticipated under microgravity conditions.

CATEGORY 2 (CONTINUED)

35)	Comparative Alloy Solidification	Dr. M.H. Johnston MSFC	Aircraft KC-135	1980	To use transparent model systems in order to investigate the gravitational in-influence on the solidification process of actual metallic systems.	A striking decrease in grain size with increasing g-field was demonstrated, confirming earlier predictions that dendrite multiplication was influenced by gravity-driven convection flows. In the low-gravity solidification of the SN-15wt%Pb alloy, the grain orientations were found to be completely isotropic, indicating probable nucleation in the center of the molten liquid. A significant increase in dendrite arm spacing was noted in the low-g metal sample, thus substantiating earlier results from the metal model systems. A tin-3wt%Bi alloy was solidified on a second flight. This had a few very large grains in constrast to the very fine grained ground based samples. Further studies of this phenomena were carried out on the KC-135. A sample was partially solidified in low-gravity and then solidification was completed during the high-g pullout. The transition in the grain structure was rapid.
36)	Solidification of Liquid Miscibility Gap Alloys Under Free Fall	Dr. L.L. Lacy MSFC Dr. G. Otto University of Alabama in Huntsville	Drop Tower Experiment		To investigate the solidification of alloy systems that exhibit a liquid phase immiscibility gap.	Fine uniform dispersions of Ga-rich particles in a Bi matrix, obtained in the freefall solidification samples solidified under normal gravity, exhibit mass separation between the Bi and Ga. The unique microstructure obtained by low-g solidification caused the resistivity of the sample as a function of temperature to exhibit a unique behavior.
37)	Influence of Gravity-Free Solidification on Microsegregation in Germanium	Dr. J.T. Yue Texas Instruments, Inc. Dallas, Tx. 75222	Skylab 32	1973	To characterize the influence of gravity-free solidification on the microsegregation of a semiconductor material.	The solute boundary layer at the growth interface is thinner in space; the solidification interface is significantly smoother and is found to be initially convex toward the melt into space. Microsegregation caused by growth rate fluctuations was eliminated in space, which improved uniformity from recrystallization. Accordingly, it may be feasible to grow higher composition alloy semiconductors such as mercury cadmium telluride and lead tin telluride, from the melt, without the interfacial breakdown that accompanies uncontrolled growth rate fluctuations, under conditions that reduce defect density due to the growth process.

CATEGORY 2 (CONTINUED)

38)	Silver Grids Melted in Space	Prof. E. Aernoudt Catholic Univ. Leuven, Belgium	Skylab	1973	To make a preliminary study of the behavior of porous material when melted and resolidified in a weightless condition. When only part of a solid body is melted in zero gravity, the tendency of the molten part to become spherical may be restricted.	The following results emerged: l) Original porosity disappeared during the melting stage. 2) Even if samples were perfectly spherical in the liquid state, their shape is altered when solidified. 3) Leveling out of impurity concentration gradients appears to be slow in molten metal when gravity induced conection is absent. 4) When only part of a solid body is melted in zero-gravity, the tendency of the molten part to become spherical may be restricted. Skylab samples differed from the ground-based test sample, in the uniform distribution of hardness values and in the nonexistence of any floating whiskers.
39)	Studies of Liquid Floating Zones	Dr.J.R.Carruthers Bell Laboratories Murray Hill, NJ 07974	Skylab II	1973	To examine the stability constraints imposed on the liquid zone in zero gravity so that crystal growth and purification processing methods may be developed for preparation of reactive material in future space flights.	The use of a zero-gravity environment removes some of the constriants imposed on the dimensions of floating zones by eliminating thermal convection and allowing more extensive geometrical modification than permitted on earth.
40)	Immiscible Alloy Compositions	Mr. J.L. Reger TWR Systems Group Redondo Beach, CA 90278	Skylab	1973	To thermally process ampoules containing materials exhibiting either liquid or solid state immiscibility in order to determine the possibility of bulk production in space.	Low gravity processed specimens exhibited better homogenization and microstructural appearances than the one gravity control specimens. The electronic behavior of the low gravity specimen were equal or superior to and the Ampoule B specimens exhibited an anomalous superconducting transition temperature approximately 2 K higher than either the one gravity control specimens or elements. In addition, the low gravity processed A and B ampoules exhibited X-ray diffraction lines not identifiable with any referenced diffraction patterns. It is concluded that low gravity processing of materials processing liquid or solid immiscibility can produce compositions exhibiting unusual metallographic and electronic behavior.

CATEGORY 2 (CONTINUED)

41)	Capillary Wicking	A.F. Whitaker MSC	Apollo-Soyuz Test Project	1975	To illustrate wicking action in a weightless environment and to determine the efficiency of transfer and wicking rates of stainless steel wicks used for fluid management in spacecraft.	Wicking of both oil and water proceeded much faster in the ASTP than anticipated on the basis of ground tests and KC-135 flight tests. The liquid was observed to rise along the corner formed by Teflon support back and mesh. Since Teflon is not normally wetted by the fluids used, this behavior was unanticipated.
42)	Monotectic and Sytectic Alloys	Dr. L.L. Lacy, MSCF Dr. C.Y. Ang, The Aerospace Corporation	Apollo-Soyuz Test Project	1975	Low-g environment was utilized by this experiment to minimize buoyancy and convective influences which in normal gravity prevent adequate synthesis of material systems in which significant, specific gravity differences exist.	The liquid-state homogenization of polyary stalline, multiphase A/sb in low-g produces major improvements in macroscopic and microscopic homogeneity, showing 4 to 20 times less of the unwanted secondary phase than in 1-g. Diffusional and liquid-state homogenization analyses indicate that gravity-induced convection can severely complicate the homogenization of 1-g melts, inducing compositional and microstructural inhomogeneity during solidification. Other unique binary systems which are difficult to synthesize on Earth because of gravity-induced effects may be advantageously processed in space.
43)	Epitaxial Growth of Single Crystal Films	Dr. M. David Lind Rockwell International Dr. R.L. Kroos, MSFC	SPAR	Oct. 1975 To May 1980	To grow exitaxial films of gallium arsenide by liquid phase epitax p(LPE) in low gravity and to compare them with films grown in normal gravity.	Epitaxial films of reasonably good quality and very nearly the thickness predicted ($\sim 1/\mu m$) for convection-free, diffusion-limited growth were produced.
44)	Studies of Model Immiscible Systems	Dr. L.L. Lacy Marshall Space Flight Center	Ground	Oct. 1979 To Oct. 1981	To use model organic immiscible systems to obtain fundamental information applicable to materials of interest in the Materials Processing in Space program in order to interpret results of flight experiments involving monotectic alloys.	The model organic systems that will be studied include monotectic and eutectic phase reactions. Many of the experiments will be performed in the lab and in the KC-135 to observe the effects, if any, on the fine scale concentration and density gradients in the liquid by the gravity vector.

CATEGORY 2 (CONTINUED)

45)	Crystal Nucleation in Glass Forming Alloy and Pure Metal Melts Under Containerless and Vibrationless Conditions	Prof. David Turnbull Harvard Univ.	Drop-Tube	June 1978 To Dec. 1982	To characterize nucleation behavior in glass-forming alloy melts. Such experiments should indicate whether formation of alloy glasses in bulk form is possible, and, if so, the necessary conditions for their formation.	It was found that the onset undercooling, ΔT_n, for copious nucleation in molten Au_4Si droplets varies widely with thermal treatments which alter the nature of the SiO_2 film on the droplet surface. However, ΔT_n as large as 1/3 of the liquidus temperature for some droplets was observed. Glass and crystallization temperatures of Au_4Si based alloys are sharply increased ($\sim 1^o$ per atom %) when Cu replaces some of the Au. The transient period for crystal nucleation has been shown to be important for glass formation in alloys, such as these, with low reduced glass transition temperatures. Drop tube experiments are being performed with droplets of Pd-Si and some Fe-based-glass forming alloys. Analysis of the crystallization shows that crystal nucleation occurs in the droplet surface and is influenced by the atmosphere in the drop tube (especially moisture).
46)	Surface Tension-Driven Flow in a Weightless Fluid	Dr. S. Ostrach Case Western Reserve University	Drop Tower		To obtain experimental data on surface-driven convection in the absence of gravity-driven flows.	Surface tension-driven flows can induce significant convection in a low-g environment
47)	Heat Flow and Convection Experiment	T.C. Banmister MSFC Dr. P.G. Grodzka, Lockheed	Apollo 14 Apollo 17	1971 to 1972	1) To determine to what extent contributions from residual vehicle accelerations and nongravity-driven convection affect heat transfer; 2) to dramatize the fact that convective flow can occur in the absense of gravity; 3) to study the onset of unstable surface tension-driven convection in the absence of buoyancy-driven convection.	On Apollo 14 the heat flow was 10 to 30% greater than predicted, which was due to crew-induced disturbances. On Apollo 17 heat flow agreed with predictions based on pure conduction.
48)	Radioactive Tracer Diffusion	Dr. A.O.Ukanwa Howard University Washington,D.C. 20001	Skylab #3	1973	To determine, in a convection-free environment, the self-diffusion coefficients for zinc and to estimate the reduction in convective mixing in Earth gravity on the basis of the zero-gravity experience.	Complications arising from convection in liquids during mass transfer on earth may be avoided or minimized by utilizing the zero-g environment. The diffusion coefficient in unit gravity was 50 times the zero-gravity diffusion coefficient of Skylab. This order of difference was attributable to unit gravity convective velocity of only 4.16×10^{-4} cm/sec in magnitude. The convective-free diffusion coefficient of Skylab was found to be $D = 9.17 \times x\ 10^{-4} \exp - (5,160/RT)$ cm^2/sec for the temperature range from 693^oK (420^oc) to 973^oK (700^oc).

CATEGORY 2 (CONTINUED)

49)	Directional Solidification of InSb Alloys	Prof. W.R. Wilcox Univ. of Southern California Los Angeles, CA. 90007	Skylab	1973	To investigate whether grain in indium antimonide crystals are generated by the compositional variations arising from hydrodynamic fluctuations in the melt.	Solidification experiments performed on InSb - GaSb alloys in both space and on Earth showed no dramatic differences in grain size; however, among space processed samples a wide range of grain sizes was observed, with no influence of growth conditions yet observed. The number of twins in the space processed samples was much less than in the earth-processed samples. Equilibrium between the growing crystal and the bulk melt was more nearly achieved in the horizontally processed ingot, because of the enhanced free convection. Gas bubbles were trapped in the ingots when the ampules were back-filled with helium. The bubbles were more evenly distributed in the Skylab ingots. Microcracks were more numerous in inhomogeneous regions of the ingots. The ingots formed in SL-3 had a smaller diameter than the tube, unlike those in SL-4. The grains were very difficult to distinguish from one another in five out of six Skylab ingots.
50)	Zero Gravity Flammability	Mr. J.H. Kimzey Johnson Space Center Houston, TX. 77058	Skylab 4	Feb 4, 1974	To note the extent of surface flame and propagation and flash-over to adjacent materials, rates of surface and bulk flame propagation, self-extinguishment and extinguishment by both vacuum and spray water.	1) Burning rates were significantly reduced 2) Surface burn was not followed by continued inward burning. 3) Ignition and extinguishment appeared to be similar to one-g. 4) Typical blue flame and smoke patterns were noted.
51)	Surface-Tension-Induced Convection	Dr. R.E. Reed Dr. Volhoff Dr. H. L. Adair Oak Ridge National Laboratory, Oak Ridge, Tenn.	Apollo-Soyuz Test Project	1975	To investigate compositional induced surface tension-driven convection in wetting and non-wetting containers in a low-g environment.	Analysis of the low-g pressure bonded samples showed that the gold moved about one-half the distance in the low temperature ampoule as in the high temperature ampoule, as would be expected from diffusion theory. Some distortion of the diffusion profile was observed near the walls; such distortion seems to depend on the sample orientation in the furnace. This suggests that either volume change or segregation effects during solidification may have been partially responsible for this effect. No difference was observed between samples processed in the steel and graphite ampoules. Apparently the melt did not wet the steel as expected. Marangoni convection offers the best explanation for the observed distribution, and therefore the "non-slip" boundary condition apparently does not apply to non-wetting materials in low-g.

CATEGORY 2 (CONTINUED)

52)	Solidification Studies of Nb-Ge Alloys	L.L. Lacy, et.al. Exxon Corporation Houston, TX Sponsor: NASA	Drop Tower	Dec. 81	To investigate the solidification of Nb-Ge alloys after deep undercooling.	Samples have been supercooled as much as 500°K below the liquidus by using free-fall conditions to eliminate crucible-induced nucleation. Final microstructures are dependent on the quenching rates at the bottom of the drop tube -- a striking extension of the B phase solubility limit.
53)	Liquid Spreading	Dr. S. Bourgeois Lockheed	Apollo-Soyuz Test Project	1975	To investigate the spreading of liquids over solid and liquid interfaces and to measure the shape of the spreading liquid and the rate of spreading.	Poor quality of the photography did not allow a definitive analysis to be made.
54)	Chemical Foams	Dr. P.G. Grodzka Lockheed	Apollo-Soyuz Test Project	1975	To investigate the stability of a liquid foam in the absence of liquid draining from thin walls; to determine whether increased stability and surface area might influence the rate at which chemical reactions take place.	Due to equipment malfunction no definitive data were obtained. However, flights in the KC-135 indicated somewhat faster reaction rates in the low-g tests than in the ground control tests.
55)	Particle Dispersion in Liquid Metal	Dr. J. Raat General Dynamics/Convair San Diego, CA 92112	Skylab	1973	To attain mixtures of liquid metals and solid particles which are stable and free of solids.	For the successful preparation of composite materials by liquid-state processing in low-g environments, two requirements are fundamental: 1) complete wetting between the component materials during the liquid processing cycle; 2) maintenance of a uniform dispersion.
56)	Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M Univ. Dr.R.L. Kroes, MSFC	Space Lab 3	June 1978 To June 1983	1)To grow TGS crystals from aqueous solution in low-gravity 2) to investigate mass transport and heat flow in a diffusion controlled growth system, and 3) to evaluate the feasible advantages and technical potential of producing solution growth crystals in space.	Single crystals of TGS were grown using a conventional low temperature solution growth method and the growth process was extensively characterized. Also, a unique technique of growing solution growth crystals by extracting heat at a programmed rate from the crystal through a semi-insulating sting was developed. TGS crystals will be grown by this technique during the Spacelab 3 Mission. Data on heat and mass transport in a diffusion-controlled system will be obtained using a laser holography technique. Analytical studies are underway to estimate growth rates in low-g condiditons.

57)	Directional Solidification of Monotectic and Hypermonotectic Aluminum-Indium Alloys under low-g	Dr. C. Potard Centre d'Etudes Nucleaires de Grenoble.	SPAR	Sept. 1976 Cont. Task	To analyze the mechanisms involved in the composite solid structure formation obtained from a miscibility gap alloy under microgravity.	It is believed that capillarity may play an important role in phase separation in low-g.
58)	III-IV Semiconductor Solid Solution Single Crystal Growth	Dr. E.R. Gertner Dr. M.D. Line Rockwell International Downey, CA	SPAR	April 1979 To Dec. 1980	To improve the quality of semiconductor substrate material used in epitaxial growth processes, since the quality of the epitaxial deposit is often limited by the quality of the substrate.	The research objective was to generate a compositionally homogeneous seed for future float zone experiments. However, technical difficulties with the original approach and recent advances in the vapor growth of III-IV solid solution led to a reassessment of the initial approach and a redirection of the program to the single crystal growth of CdTe, a III-IV compound.
59)	Foam Copper	Prof. R.B. Pond J.M. Winter Marvaland, Inc. NAS8-33021	SPAR	April 1978 To Oct. 1980	To determine if entrapping gas bubbles during solidification in microgravity will result in a metal "foam".	A deoxidized copper specimen is prepared with a homogeneous dispersion of fine graphite and a separate source of copper oxide. At 100°C to 1150°C, only the graphite remains solid serving as nucleation sites for gas bubbles.
60)	Mass Transfer in Electrolytic Systems Under Low Gravity Conditions	Dr. C. Riley, et.al., Univ. of Alabama Huntsville	KC-135 Aircraft	Sept. 1979 To June 1982	To achieve the electroformation of materials with improved or more desirable properties and to better understand the electrode position process.	Electrodeposition cells are being utilized to study simple metal-in/metal-out reactions using cobalt and copper. The density flow patterns between electrodes with both a vertical and horizontal configuration are being bench characterized using interfermetry detection. These results are being compared to those determined for the same cells under reduced gravity conditions ($\sim 10^{-2}$g) produced during parabolic, free-fall flights of a KC-135 aircraft. A special vibration free interfermeter was developed to monitor flow during these flights. Studies with neutral buoyancy particles are to be used to model the transport of neutrals under low gravity conditions.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY 3

	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
61)	Electrophoresis Technology	Dr. R. S. Snyder MSFC	Ground		1) To analyze the fluid and particle motions during continuous flow electrophoresis by experimentation and computation 2) to characterize and optimize electrophoretic separators and their operational parameters; and, 3) to separate biological cells using apparatus that have been characterized or modified to perform in a predictable manner and according to procedures that have been developed to yield improved separation.	The results may be summarized as follows: (1) experiments were designed to decouple or minimize the fluid effects due to the flow process, electrokinetic effects, and temperature gradients; (2) transparent electrophoresis chambers were built to allow measurement of internal and wall temperature while observing flow perturbations; (3) techniques were developed to map the temperature and flow fields in the chamber with small disturbance to the process; (4) the sensitivity of these chambers to lateral temperature gradients was measured and a new, all-metal chamber was designed to incorporate the improvements suggested by these experiements, (5) analysis yielded results that reproduce flow distortions observed in experimental chambers, (6) the DESAGA FF48 and Beckman continuous flow electrophoresis chambers were compared, using standard particles (fixed red blood cells) under various operating conditions; (7) optimum operating parameters for resolution and throughput were established and compared; and (8) these optimized conditions are being used for the separation of biological cells and macromolecules with reproducibility potential.

62)	Surface Tensions and their Variations with Temperature and Impurities	S. C. Hardy National Bureau of Standards	Ground	April 1977 Cont. Task	Traditional sessile drop surface tension measurements are being used in conjunction with Auger spectroscopy and other modern surface analytic techniques to study the thermodynamics and chemistry of liquid metal interfaces.	Current research is being conducted on the application of Auger spectroscopy to liquid metal surfaces. These experiments are being conducted in a conventional Auger spectrometer with the use of a vertical cylindrical mirror analyzer and a horizontal sample manipulator. The samples under consideration are sessile drops which permit the surface tension to be measured simultaneously with the Auger spectrum. Initial work with gallium drops has been promising because it was found that the surface of the drop can be cleaned by sputtering with argon ions. Fluid flows are generated in the sputtering which draws solid impurities such as oxides into the ion beam where they are sputtered away. The mechanism generating this flow is not yet identified.
63)	Oxide Glass Processing in Space	Mr. R.A. Happe Rockwell International Space Division	Skylab	1973	To highlight experimental work conducted over the years leading to the production of useful new optical glasses in space.	Recent experiments, which have resulted in the formation of 1/4 inch diameter glass samples from two compositions, suggest that containerless melting and cooling as envisioned for space operations are of real technological significance.

64)	Purification and Cultivation of Human Pituitary Growth Hormone-Secreting Cells	W. C. Hymer Penn State Univ.	Ground	June 1981 To June 1982	To address the problem of 1) separation of the pituitary growth hormone cell, 2) its maintenance *in vitro*, and 3) the role that gravity plays in establishing limits at these current lab technologies.	A human pituitary column perifusion method was developed to sustain human growth hormone (hGH) release from pituitary tissue over extended periods (1-3 days). On the basis of experimental results from 144 human pituitary glands removed 1-18 hours, postmortem, it was found that prostaglandin E_1 (10^{-9}M) or epinephrine (10^{-9}) stimulates release of a "GRF" from rat hypothalmi which is, in turn, capable of sustaining hGH release for at least 24 hours. Tissue samples stained immunocytochemically for hGH cells reveal large numbers of well-preserved cells in this experimental protocol. These results support the notion that the human postmortem pituitary gland contains functional growth hormone cells. Results from numerous experiments demonstrate that we can prepare 15×10^{-3} cells/mg postmortem human pituitary tissues. These cell preparations are 80% viable, and by electron microscopy contain membrane and granule systems characteristic of intact tissue. Concerted efforts were made to separate GH cells from both rat and human pituitaries by chemistry gradient electrophoresis. Results indicate that somatotrophs (GH cells) apparently have low electrophoretic mobilities, and possibilities for their eventual purification by this technique appear encouraging. Finally, a methodology has been developed for the implantation of human pituitary cells in rats. With this methodology it should be possible to assess a function of hGH cells *in vitro*, and eventually isolate hGH from the animal.

65)	Undercooling Studies in Metastable Peritectic Compounds	M.B. Robinson Marshall Space Flight Center	Ground	March 1979 To March 1982	To investigate undercooling and containerless solidification of metastable superconducting alloys Nb_3Ge and Nb_6Al pure metal melts such as Nb.	Undercooling is being measured for the NbGe alloy drops with results showing that the Nb 18 a/o Ge drops undercooled 500 K, while the Nb 22 a/o Ge drops undercooled 300 K. These undercoolings do not represent the maximum extent possible since these drops undercool the complete length of the drop and nucleated only after reaching the catcher. An increase in the transition temperature of the heavily undercooled NbGe drops results in a measured transition temperature of 10K which is 4K above the cast materials. The increase indicates that at least some of the metastable A15 structure has been formed. The presence of the metastable A15 phase has been confirmed by X-ray diffraction, compositional analysis under EDAX and further microstructural analysis.
66)	Vapor Growth of Alloy-Type Crystals	Dr. Herbert Weidemier Polytechnic Institute	Ground	March 1978 To March 1983	To investigate, through systematic ground-based studies, the effects of gravity-crystals of alloy-type semiconductors; to define optimum conditions for the growth of these materials in a microgravity environment, and to perform crystal growth studies in space.	Present results reveal that the surface morphology and chemical homogeneity of Hg_8Cd_2Te crystals obtained under vertical stabilizing conditions are improved relative to crystals grown under horizontal conditions. The crystal quality of $CuInS_2$ shows similar improvements for the horizontal ampoule configuration with decreasing pressure (decreasing convective interference) of of the system. The combined results of ground-based studies will lead to the definition of optimum growth conditions for the actual space experiments.

CATEGORY 3 (CONTINUED)

67)	Fluid Dynamics of Crystallization from Vapors	Dr. F. Rosenberger Univ. of Utah Salt Lake City	Ground	June 1978 Cont. Task	To obtain a fundamental insight into the complex physiochemical fluid dynamics of closed ampoule vapor crystal growth processes to the extent that a desired set of crystal growth conditions can be designed in advance.	Numerical modeling of vapor transport in vertical ampoules shows that diffusion fluxes, in viscous interaction with the wall, establish density gradients normal to the main transport direction. These density gradients act convectively, destabilizing even in ampoule orientations which, classically, were considered convection free (e.g., "heating from top"). Also, it was demonstrated that the convection behavior in crystal growth ampoules can not be extrapolated from known solutions to fluid dynamically "similar" monocomponent (pure) systems. The net transport across the vapor space causes drastic changes as compared to convection patterns in cylinders with impermeable end faces. It was found experimentally that thermal diffusion in ampoules acting convectively were more destablizing than in laterally unbound geometries. Modeling of vapor transport across a horizontal cavity has shown that at lower transport rates earlier, simplifying treatments (Klosse-Ullersma, KU), because of fortuitous cancellation of errors, give reasonable results for two-dimensional systems. However, laser Doppler anemometry studies of the convective velocity fields in inclined and horizontal ampoules revealed three-dimensional features of the flow that had generally not been accounted for in modeling. Titrometric and vapor pressure studies have shown that deviations in stoichiometry of mercuric iodide ($HgI_{2}+x$) can extend to $x = -3 \times 10^{-3}$. No excess in iodine, i.e. $x > 0$, could be detected in vapor and solution-grown samples obtained from various sources.
68)	Experimental and Theoretical Studies in Wetting and Multilayer Absorption	Dr. M.R. Moldover Dr. J.W. Schmidt Dr. J.W. Cahn National Bureau of Standards	Ground	April 1981	To use optical techniques to measure the thickness of the layer which intrudes between the upper liquid phase and the vapor at the liquid vapor interface above 3 different transparent binary solutions and one transparent tertiary solution	Measured thickness range from 60A°-400A°. A phase transition, at which the thickness of an intruding layer increases from less than 20A° to approximately 400A° as a two phase liquid sample is heated less than 0.05°C, was discovered. A theory was developed for phase equilibria among grain boundary structures and for transitions among various grain boundary phases.

CATEGORY 3 (CONTINUED)

69)	Glass Shell Manufacturing in Space	Dr.Robert L. Lolen KMS Fusion, Inc. Ann Arbor, Mich.	Ground	Dec. 1978 To Dec. 1981	To develop a detailed understanding of the chemical and physical processes involved in the formation of uniform, high-quality spherical glass shells.	The temperature regimes where major transformations occur in the shell starting materials (metal-organic gels) were identified by using a combination of thermal, analytical techniques. The gases generated by pyrolysis of the gel were quantitatively characterized by gas chromatography and pressure tests. Computerization of a mathematical model of the heat transfer mechanisms will be used to bring it into line with the results from a series of controlled drop tower furnace experiments to be done with fully characterized and standardized gel power pellets.
70)	Advanced Methods for Preparation and Characterization of Infrared-Detector Materials	Dr. J. G. Broerman et.al.,McDonnald Douglas Research Labs	Ground	Dec, 1978 To Dec. 1982	To quantitatively establish the characteristics of Hg_{1}-x cdx Te as grown only on Earth (1-g) as a basis for subsequent evaluation of the material processed in space, and to develop experimental, theoretical and analytical methods required for such evaluation.	Theoretical models and computer programs specific to $Hg_{1-x} Cd_x Te$ were developed for calculations of charge-carrier concentrations, Hall coefficient, Fermi energy, and conduction electron mobility as functions of x, temperature, ionized-defect and neutral-defect concentrations. A comparison of calculated results with available experimental data indicated that longitudinal optical-phonon and charged and neutral defect scattering are the dominant mobility limiting mechanisms.

71)	Defect Chemistry and Characterization of (HgCd) Te	Dr. H.R. Vydyanath Honeywell	Ground	Dec. 1978 To March 1982	To study the nature and concentration of the lattice defects incorporated into $(Hg_{01-x}Cd_x)$ Te Alloys as a function of the physiochemical conditions of preparparation.	At the end of the 24 month period of the program, significant accomplishments have been made toward understanding the nature of lattice defects and the mode of incorporation of different dopants. For the first time in the literature, the defect structures of undoped $Hg_{0.6}Cd_{0.4}Te$ (s), copper doped, indium doped, iodine doped, and phosphorus doped $Hg_{0.8}Cd_{0.2}Te$ (s) have all been established. The native acceptor defects have been found to be doubly ionized in both $Hg_{0.6}Cd_{0.4}Te$ (s) and $Hg_{0.8}Cd_{0.2}Te$ (s). Native donor defects are found to be negligible in concentration in these alloys and the origin of p-type to 7 n-type conversion has been shown to be due to residual foreign donors and not due to native donor defects. Of the dopants studies, copper and indium were found to occupy only Hg lattice slits acting with single acceptor and donor electrical activities respectively, whereas iodine is found to act as a single donor occupying only Te sites. A large concentration of indium is found to be incorporated in In_2Te_3 with only a small fraction acting as donors. Crystals doped with iodine are found to be saturated with the metal iodide, with a large fraction of iodine being paired with the native acceptor defects. Crystals doped with phosphorus behave amphoterically, acting as a donor on Hg lattice sites and as an acceptor interstitially and on Te lattice sites. Thermodynamic constants have been established for the incorporation of the native defects as well as the different dopants. These constants satisfactorily explain all the experimental results.

72)	Ultimate Intrinsic Coercivity $SmCo_5$ Magnet	Dr. Dilip Das Charles Stark, Draper Laboratory Dr. R.T. Frost General Electric	Ground	Sept. 1979 To July 1982	To produce Sm-Co magnets of reasonably high maximum energy product with intrinsic coercivity.	In preparation for the design of a high quality comminution and encapsulation chamber, some preliminary comminution experiments in a laminar flow nitrogen glove box are being performed. The oxygen pickup in the above powder has been reduced by 60 percent over the power prepared in the air. Based on this encouraging result, using a high quality chamber in a pure quiescent nobal gas should lower the oxygen content to a few decades of ppm instead of the 0.6 weight percent in the state-of-the-art magnets. A comminution chamber was built by an outside vendor and has just been installed at the Draper Laboratory. The chamber is capable of attaining 10^{-6} torr pressure, and can be back filled with purified Argon gas with an oxygen level of 0.1 ppm by weight. Experiments to achieve powder comminution compaction and encapsulation of compacts in the oxygen-free atmosphere inside the chambers will commence soon. Further experiments in R.F. levitation melting of $Sm\,Co_5$ alloy do not result in significant lowering of oxygen content. However, some $SmCo_5$ alloys with very low oxygen and other contaminant contents have been produced using the expertise and facilities at the Ames Laboratory of Iowa State University.
73)	Studies of Model Immiscible Systems	D.O. Frazier et al MSFC	Ground	Oct. 1979 To Oct. 1982	To use model organic immiscible systems to obtain fundamental information applicable to two-phase systems in general, and to apply this understanding to materials of interest in the Materials Processing in Space Program in order to interpret results of flight experiments involving monotectic alloys.	Data with respect to solidification of succinonitrile/water solutions are thus far consistent with critical point wetting behavior and Marangoni effects. There is experimental evidence that wetting phenomena are observable by holographic photography. Solid-liquid interfacial free energy differences are, in principle, accessible by film pressure (via ellipsometry) measurements. Viewing holographic studies and interfacial free energy measurements in light of segregation profiles of model solidified ingots should yield valuable verification of operational limits.

CATEGORY 3 (CONTINUED)

74)	Directional Solidification of Liquid Miscibility Gap Materials	Dr. M.H. Johnston Marshall Space Flight Center	Ground	To identify the influence of gravity on the aligned structure in liquid miscibility gap materials. This includes establishing the true monotectic composition and determining the solidification machanism's possible dependence on undercooling.	Al-Bi and Al-Pb monotectic and off-monotectic materials will be solidified isothermally and unidirectionally. DTA measurements will determine monotectic compositon. Undercooling prior to phase separation will be given special attention, and a correlation between quantitative composition and melting point/undercooling data will establish the solidification sequence.
75)	Analysis of the Float Zone Process	Prof. R.A. Brown Mass. Institute of Technology Cambridge, MA. Sponsor: NASA	Ground base	To understand the interaction of heat, mass, and momentum transfer in the floating zone method for growing single crystal from the melt.	New computer-aided methods based on finite-element techniques have been developed for analyzing the interaction between heat and mass transfer and melt/solid interface shape in melt growth processes. Techniques for analyzing rotation induced flows extended to study the combined effect of rotation and surface-rotation convection flows which are likely to exist in low-g experiments.
76)	Solutal Convection and Its Effects on Crystal Growth and Segregation in Binary and Pseudo-Binary Systems with Large Liquidus-Solidus Separation	Dr. Edith D. Bourret MIT	Ground	To theoretically and experimentally study the effects of solutal convection on segregation in binary and pseudo binary systems with large liquidus solidus separation (i.e. Ge-Si, Hg_1-xCdxTe, PbxSa$_1$-xTe).	These studies are aimed at advancing the theoretical framework for solidification and at optimizing crystal growth experiments to be conducted in a reduced gravity environment.
77)	Transient Convective Heat Transfer in Zero Gravity	Dr. V. Arp Dr. R. Noble National Bureau of Standards Boulder, Colorado	Ground	To separate the gravitational contribution from dynamic heat and mass transfer measurements, thus allowing a more accurate comparison with theory, and improved engineering correlations.	Two types of mass transfer experiments are envisioned. In the first, an ionic solution is initially isolated from a pure component. The barrier is then removed and the resulting diffusion monitored. In the second type of experiment, an ionic solution would be exposed to an external applied field and the resulting diffusion monitored.
78)	Study of Eutectic Formation	Dr. W. R. Wilcox Clarkson College	Ground	To investigate the theoretic influence of convection on lamellar spacing of a eutectic and to develop a technique for revealing the longitudinal microstructure of the MnBi-Bi eutectic.	A computer program computes the concentration field in the melt-- with a linear velocity field present- in front of a plane-front lamellar eutectic.

CATEGORY 3 (CONTINUED)

79)	Transient and Diffusion Analysis of HgCdTe	Dr. J. Creed Clayton Semtec, Inc. Huntsville, Ala. Sponsor: NASA	Ground	Dec. 1980 To Dec. 1981	To analyze the directional solidification of the alloy systems HgCdTe in order to obtain optimim processing conditions for crystal growth.	Directional solidification of HgCdTe has been modeled and the results of this model have been applied to the initial and final solute segregation transients in order to estimate an effective diffusion constant.
80)	Blood Flow in Small Vessels	Dr. G. R. Cokelet Dr. H. Meiselman Dr. H. Goldsmith	Ground		To study the flow of blood under low shear stresses in red sidementation under zero gravity by obtaining ground-based data for the establishment of flight test conditions.	The task is divided into three parts: 1) Preparation and characterization of red cell suspensions, 2) Optimization of the time-stability of cells in suspension, 3) Production of test flow sections and the testing of potential flight components.
81)	Advanced Methods for Preparation and Characterization of Infrared-Detector Materials	Dr. S.L. Lehoczky Dr. F.R. Szofran Dr. J. G. Broerman, McDonnell Douglas Research Labs Sponsor: NASA	Ground	Dec. 1978 to Dec. 1981	To quantitatively establish the characteristics of Hg1-x CdxTe as grown on Earth (1-g)as a basis for subsequent evaluation of the material processed in space, and to develop experimental, theoretical, and analytical methods required for such evaluation.	Theoretical models and computer programs specific to Hg1-x CdxTe were developed for calculations of charge-carrier concentrations, Hall coefficient, Fermi energy, and conduction electron mobility as function of x, temperature, an ionized-defect and neutral defect concentrations. A comparison of calculated results with available data indicated that longitudinal optical-phonon and charged and neutral defect scattering are the dominant mobility limiting mechanisms.
82)	Analysis of the Float Zone Process	Prof. R.A. Brown MIT	Ground		To achieve a fundamental understanding of the interaction, of heat, mass, and momentum transfer in the floating zone method for growing single crystals from the melt.	New computerized methods based on finite-element techniques have been developed for analyzing the interaction between heated and mass transfer and melt/solid interface shape in melt growth processes.
83)	Solutal Convection During Directional Solidification	S.R. Coriell R.S. Schaeffer National Bureau of Standards	Ground	April 1977 Cont. Task	To calculate and measure the effects of convection, caused by simultaneous temperature and concentration gradients, on directional solidification, including a determination of segregation effects in experiments done on Earth and estimation of the effect of microgravity and magnetic fields in avoiding such convection.	This research will delineate the conditions under which gravity-griven convection will occur during constant velocity unidirectional solidification. Numerical algorithms are being developed to solve the non-linear fluid flow, heat flow, and diffusion equations in two spatial dimensions.
84	Fluid Motion in a Low-G Environment	Dr. P.G. Grodzka Lockheed Missiles and Space Company	Skylab	1973	To review the state of knowledge of fluid motions in low-g environments; to outline the dimensional analysis approach used to assess the relative importances of various driving forces for fluid flow in Skylab material processing experiments.	Fluid motions as a function of gravity level are of concern in low-g space processing applications because fluid motions can affect not only the shapes of fluid masses but also internal profiles of temperature concentration, and immiscible particle distribution, which can predict low-g thermoacoustic convection in gasses, given a sufficiently high heating rate.

85)	Electrostatic Control and Manipulation of Materials for Containerless Processing	Dr. D.D. Elleman Dr. W. K. Rhim Jet Propulsion Laboratory	Ground	October 1978	To develop electric field positioning/ manipulation techniques and technology for the containerless processing of materials in bulk and dispersed forms.	Task studies include: electric field feed back control for bulk sample positioning, methods and limitations of electric field confinement, electrode configuration, electro-hydro dynamics of both charged and neutral drop systems, and dynamics and stability of charged particle arrays.
86)	Liquid Metal Diffusion in Solubility Gap Materials	Prof. R.B. Pond J.M. Winter Marvaland, Inc. Westminster, Md.	Ground	April 1978 To Sept. 1980	To measure the diffusion rates of two liquid metals. The intermediate objective is to verify or disprove the suspicion that determining diffusion constants of solubility gap liquid metals in one "g" experiments will lead to erroneous results due to density-driven convection motion, -- which would require experimentation in microgravity.	A new diffusion geometry has been devised which permits the establishment of a sharp, oxide-free, and void-free interface between the diffusion couples at a well-defined time after the melts equilibrate at a selected temperature.
87)	Analytical Approach to Modeling of Heat Flow in Bridgman-Type Crystal Growth	Dr. R.J. Nauman Ms. Ernestine Cothran Marshall Space Flight Center, Ala	Ground	Oct. 1980 To May 1981	To develop an analytical approach to the modeling of heat flow in Bridgman-type crystal growth. This analysis is particularly valuable for establishing control conditions for meeting processing requirements, for performing sensitivity analyses, and for performing engineering trade studies.	One-dimensional models have been used to estimate the thermal profiles, determine the position and motion of the growth interface, and assess the axial thermal gradients in the sample as functions of furnace and sample parameters, sample insertion length, and sample motion. A two-dimensional analysis has also been developed which can accommodate different thermal properties of the sample in the melt and solid phases and can locate the position and determine the shape of the solidification interface in a 3-zone furnace which includes an insulated or adiabatic zone. It has also been shown that the maximum axial gradient in a long cylindrical sample that can be obtained by the Bridgman technique is approximately 2/3 times the difference between the hot and cold end temperatures divided by the sample radius.
88)	Direct Observation of Interface Stability	Prof. W.A. Tiller Prof. R.S. Fiegelson Dr. D. Elwell Stanford Univ.	Ground	Dec. 1978 To Jan 1982	To test the theory with the experimentation on a model system, including a measurement of all significant material parameters of the system.	The parameters to be measured are: (1) diffusion coefficients of the solutes in the liquid, (2) phase diagram and effective distribution coefficents for the solute, (3) liquidus slopes for the chosen solutes, (4) thermal conductivities and diffusivities for both liquid and solid, and (5) the solid-liquid interfacial energy.

89)	Physical Phenomena in Containerless Glass Processing	Dr. R.S. Subramanian, Dr. R. Cole Clarkson Clarkson College of Technology	Ground base	Dec. 1977 to Dec. 1982	To study the behavior of gas bubbles inside drops of model fluids and molten glasses in free fall, focusing on their migration and interaction.	The results of the experiments are expected to be of use in the development of techniques for mixing and firing glasses in space and in providing a better understanding of how microballoons are formed.
90)	Fluid Dynamics of Crystallization from Vapors	Dr. F. Rosenberger University of Utah Salt Lake City	Ground	June 1978 To May 1981	To obtain a fundamental insight into the complex physiochemical fluid dynamics of closed ampoule vaopr crystal growth processes; to synthesize ultrapure mercuric iodide and the vapor composition (stoichiometry) required for the growth of mercuric iodide high resolution radiation detector crystals.	Numerical modeling of vapor transport in vertical ampoules has shown that diffusion fluxes establish density gradients normal to the main transport direction. These density gradients act convectively destabilizing even in ampoule orientations which were consdiered convection free.
91)	Growth of Solid Solution Crystals	Dr. L.R. Holland Athens State College, Athens Alabama Dr. A.F. Witt MIT Dr. D.B. Schenk, BMD-ATC	Ground followed by Flight Experiments	Oct. 1977 to Oct. 1982	To determine the conditions under which single crystals of solid solutions can be grown from the melt in a Bridgman configuration with a high degree of chemical homogeneity. The central aim of this program is to assess the role of gravity in the growth process and to explore the possible advantages for growth in the absence of gravity.	The problems of purity and containment in quartz ampules were resolved. The necessary purity and the resulting absence of chemical attack on the quartz are achieved by obtaining ultrapure starting material and loading by distillation. The structural integrity of the ampoules at the high vapor pressures associated with growth of this system was demonstrated. Crystals were grown by the Bridgman method and analyzed by the energy dispersive X-ray technique (Kevex). Composition was determined longitudinally and radially. These compositional profiles are being analyzed by one-dimensional models. In addition to the basic studies, thermal profiles were determined to obtain the optimum growth environment for the HgCdTe material.
92)	Float Zone Experiments in Space	Dr. J. D. Vethoeven Ames Laboratory Iowa State Univ.	Ground	Oct. 1981 To Oct. 1982	To determine if surface tension-driven convection in a float zone can be controlled or eliminated by means of surface film; and, to investigate solute distribution and measure liquid diffusion coefficients in floating zones.	Experiments will consist of measuring oxide layer thicknesses upon interface shapes, the radial and longitudinal composition profiles, temperature profiles and the possible onset of ancillary temperatures; evaluating solute profiles in the initial transient zones and the quenched zones.
93)	Vapor Phase of PbSnTe	JA Zoutendyk Jet Propulsion Laboratory	Ground base	March 1981 To March 1982	To experimentally study the gravity-driven convection effects in the growth of PbTe and CdTe crystals by physical vapor transport.	The binary compound semiconductors under experimentation are important as substrate material for the epitaxial growth of PbSn Te and HgCdTe layers, respectively, for infrared detector fabrications.

CATEGORY 3 (CONTINUED)

94)	Growth of Solid Solution Crystals	Dr. S.L. Lehoezky, MSFC Dr. F.R. Szofran, MSFC Dr. L.R. Holland, UAH Dr. J.C. Clayton, Semtec Dr. D.C. Gillies, Semtec	Ground base followed by Flight Experimentation	Oct. 1977 To Oct. 1982	To determine the conditions under which single crystals of solid solutions can be grown from the melt in a Bridgman configuration with a high degree of chemical homogeneity. The central aim of this effort is to assess the role of gravity in the growth process of single crystals of solid solutions and to explore the possible advantages for growth in the absence of gravity.	Experimental facilities have been established for the purification, casting and crystal growth of the alloy system. Crystal are being grown by the Bridgman--Stockbarger/method and are analyzed by various experimental techniqus to evaluate the effects of growth conditions on the longitudinal and radial compositional variations and defect densities in the crystals.
95)	Dendritic Solidification at Small Supercoolings	M.E. Glicksman Rensselaer Blytechnic Institute	Ground	March 1977 To June 1982	To obtain information relating to the kinetic and morphological behavior of systems solidifying at small supercoolings with respect to the role of convective and diffusive transport and the influence of gravity.	These studies provide important data on the fundamentals of solidification at normal terrestrial and reduced gravitational levels. The large data base now established for high-purity succinonitrile (SCN) permitted the most comprehensive check of diffusional dendritic growth theory and the development of scaling laws permitting the extension of these theories to many other material systems.
96)	Fluid Dynamics Numerical Analysis	Dr. L.W. Spradley Dr. J. Robertson Lockheed Missiles and Space Company	Ground	August 1979 To August 1982	To compute transient thermal convection for cases of importance to materials processing in space. This includes problems too difficult for analytical solutions.	Currently underway is a calculational effort to determine the effect of container shape on the magnitude of microgravity convection.
97)	Containerless High Temperature Property Measurements by Atomic Fluorescence	Dr. P.C. Nordine Yale University	Ground	June 1980 To May 1983	To measure high temperature properties in containerless experiments using laser excited atomic fluorescence, and to develop new techniques for an earth-based study of candidate space labs high temperature experiments in MPS applications.	Specimen vapor pressure, temperature, or evaporation rate, gas phase transport properties, or gas phase reaction rate constants are being determined.
98)	Ultrapure Glass Optical Waveguide Development in Microgravity by the Sol-Gel Process	Dr. S.P. Mukherjee Battelle Columbus Labs	Ground	June 1982 To June 1983	1) To study the homogeneity of gels and gel-derived in the oxide systems which are potentially important in the field of optical waveguild applications 2) to study the glass formation ability of certain compositions in the selected melting of homogenesis multicomponent noncrystalline gels. 3) to study the influence of impurities obtained from the containers of the glass formation ability and 4) to perform containerless melting of ultrapure multicomponent gels and evaluate their purity and crystallinity.	Results of the studies of the oxide systems SiO_2-GeO_2, SiO_2-TiO_2, and GeO_2-PbO/Bi_2O_3 are being critically analyzed for the selection of one particular system for the containerless processing of ultrapure gels in the microgravity environment of space.

CATEGORY 3 (CONTINUED)

99)	Aligned Magnetic Composites	Dr. D.J. Larson, Jr. Grumman Aerospace Corp.	Ground	July 1978 To July 1983	To contribute to an understanding of the role of convection on plane front solidification of eutectic and peritectic composites and the relationships between morphology and magnetic properties; to assess the commercial potential for processing binary composites in low-g.	The low-g orbital environment will be utilized to study diffusion controlled solidification for experimental regimes that would be described as convective/diffusive regimes terrestrially. In addition, the relationships between solidification processing parameters, solidification microstructures, microchemistry and magnetic properties are being studied.
100)	The Influence of Gravity on the Solidification of Monotectic Alloys	Dr. A. Hellawell Michigan Technological Univ.	Ground	Sept. 1980 To Sept. 1983	To examine the monotectic reaction, using directional solidification methods, in order to obtain aligned composite structures; to identify the gravitational influence on separating two liquids below a miscibility gap and incorporating them within a duplex growth front.	The systems under examination include Al-In, Cu-Pb, Al-Bi, Cd-Ga, and a transparent analogue $(CH_2CN)_2 - H_2O$ as well as the ternary systems Al-In-Sn, Cu-Pb-Al and Cd-Ga-Al. The transparent analogue system is being examined in a temperature gradient stage on an optical microscope in order to study the detailed form of the duplex, solid + liquid growth front.
101)	Theoretical Studies of the Surface Tension of Liquid Metals	D. G. Stroud Ohio State University	Ground	Feb. 1982 To Feb. 1984	To develop a theoretical understanding of the surface tensions of liquid metals, and of their temperature and concentration derivatives.	The approach is first principles: starting from the pseudo potential which characterizes the conduction-electron ion interaction in a metal, elements of the electronic theory of metals and of classical statistical mechanics/ of liquids are used to calculate surface tensions of pure liquid metals as a function of temperature, and the widths of the surface density profiles.
102)	Measurement of the Properties of Tungsten at High Temperatures	Dr. J. Margrave Rice University	Ground	Nov. 1978 To March 1985	To measure the thermophysical properties of tungsten and tantalum using containerless techniques.	Heat capacities are determined from cooling curves, and/or dropping the molten metals in a drop calorimeter. Enthalpy increments and heat capacities and emissivities are being measured.
103)	Fusion Target Technology	Dr. T.G. Wang Jet Propulsion Laboratory	Ground	Oct. 1979 Cont. Task	1) To study the physical processes that are associated with the fabrication of inertial confinement fusion (ICF) targets in a weightless environment, 2) to determine jointly with DOE centers the need for extended 0-g in future production of ICF targets. 3) to provide technological information to DOE centers.	A study of the fluid dynamic process and various temperature levels and gradients as they pertain to pellet fabrication will follow along with the construction of Earth-based high temperature and high temperature gradient drop towers.

CATEGORY 3 (CONTINUED)

104)	Binary Miscibility Gap Systems	Dr. V.A. Schmid National Bureau of Standard	Ground	April 1981 Cont. Task	To exploit the thermocapillary migration effect in the design of a controllable heat valve which is the thermal analog of an electronic vacuum triode.	Further theoretical studies are planned that take into account the effect on thermocapillary migration of a gradient in chemical composition of the host fluid.
105)	Interfacial Destabilization in Metal Alloys	Y. Malmejac J. J. Favier Laboratoire d'Etudes de la Solidification Centre d'Etudes Nucleaires de Grenoble	Ground	Jan 1980 Cont. Task	To study the destabilizing mechanisms that affect a crystal growth interface; to obtain information on destabilizing morphologies in the steady and transient states and on growth kinetics behavior; and to attempt to separate the influence of liquid phase instabilities from the interface instability.	These effects will be studied by directional solidification experiments on metal alloys with moderate melting temperatures.
106)	Crystal Growth of Device Quality GaAs in Space	Prof. Gatos Dr. Jacek Lagowski MIT	Ground	April 1977 Cont. Task	To establish relationships among crystal growth parameters, materials properties, electronic properties and device applications of GaAs. This will constitute a necessary step toward insuring successful processing of GaAs under zero gravity conditions.	The research task includes the detailed study of the mechanisms of GaAs crystal growth from the meH and from solution, and of the development of techniques for the characterization of materials and electronic properties on a microscale.
107)	Advanced Containerless Processing Technology	Dr. T.G. Wang Jet Propulsion Laboratory	Ground	October 1970 Cont. Task	l) To study the contactless positioning and manipulation of a high temperature acoustic chamber 2) to provide design information on a flight version of this chamber for materials science studies in a contactless and zero gravitation environment 3) to provide a set of ground-base facilities to perform precursor experiments.	The approach is through experimental and theoretical studies of: (1) acoustic positioning and manipulation capabilities, (2) various acoustical geometries, (3) loss mechanisms associated with high-intensity and high-temperature acoustic waves, (4) an aeroacoustic positioning system. (5) a liquid-liquid positioning system (6) positioning and manipulation capabilities of a KC-135 acoustic module.
108)	Transient Thermal Convection in Low-g	Dr. R.F. Dressler NASA HQ	Ground	Jan. 1980 Cont. Task	To obtain analytical solutions for transient and periodic convection flows for arbitrary low-g excitations with imposed thermal gradient in cylinders and cubes for both 2-b and 3D flows.	Developed anaylitical approach to the computation of convetion parameters.
109)	Marangoni Effect in Crystal Processing	Dr. Arthur Fowle A. D. Little Cambridge, MA	Ground	March 1978 to Dec. 1980	To measure the freezing interface morphology and the velocity and temperature fields on the surface of a molten zone in a cylindrical sample of gallium doped germanium in a crystal growing configuration.	This experiment will be carried out under under conditions in which gravity-induced convection is made negligible in a micro-gravity environment. The concommitant flows driven by surface tension gradients (the Marangoni Effect), which are predicted to upset the diffusion-controlled process ideal, are to be examined.

CATEGORY 3 (CONTINUED)

110)	Solution Growth of Crystals in Zero-Gravity	Dr. R. B. Lal Alabama A&M University Dr. R. L. Kroes MSFC	Ground	To June 1983	1) To grow TGS crystals from aqueous solution in low-gravity, 2) to investigate mass transport and heat flow in a diffusion-controlled growth system, and 3) to evaluate the possible advantages and technical potential of producing solution growth crystals in space.	In a ground-based facility, single crystals of TGS were grown using a conventional low temperature solution Research on growth method and the growth process was extensively characterized. Also, a unique technique of growing solution growth crystals by extracting heat at a programmed rate from the crystal through a semi-insulating sting was developed. TGS crystals will be grown by this technique during the Spacelab 3 Mission. Data on heat and mass transport in a diffusion-controlled system will be obtained using a laser holography technique. Analytical studies are underway to estimate growth rates in low-g conditions.
111)	Electrophoretic Separation Based on Immunomicrospheres	D. A. Rembaum Jet Propulsion Laboratory California Inst. of Technology Pasadena, CA	Ground	1978 Continuing Task	1) To demonstrate a new concept for cell separation based on labeling specific groups of cells with immomicrospheres and isolating the labeled cells and unlabeled cells by means of electrophoresis, and 2) to demonstrate that cell separation of immunologically labeled cells is more efficient in the space environment than on Earth.	Immunomicrospheres are submicron-functionalized, polymeric particles counted with antibodies or other reagents capable of recognizing and binding to individual cell types. Ground based research has shown that by choosing microspheres of a mobility at least 20% lower than that of the target cell, it was possible to electrophoretically separate human B and T lymphocytes, a separation which is impossible without immunomicrospheres. This type of separation should be considerably improved in the absence of gravity.
112)	Countercurrent Distribution of Biological Cells	Dr. E. E. Brooks Univ. of Oregon Health Sciences Center NAS8-33575	Ground	Nov. 1979 To Nov. 1982	To develop and understand cell partition in a reduced gravity environment, as a sensitive, analytical and high resolution preparative procedure for biomedical research.	It was found that phase separation, as indicated by optical cleaning, occurs rapidly under the influence of a modest electric field, but that turbidity then reappears after a few minutes. By isolating the upper and lower halves of the sample chamber at different times after mixing, in the presence or absence of an electric field, it was found that most of the phase separation occurs before a large change in turbidity is detected, implying that the optical signal is dominated by the haze of small drops left behind after the bulk of the phase volumes have separated. The direct sampling experiments have demonstrated unequivocally that low electric fields (0.5 v am^{-1}) enhance the rate at which the phases separate, even in the presence of unit gravity.

CATEGORY 3 (CONTINUED)

113)	Microgravity Silicon Zoning Investigation	Dr. E. L. Kern, Consultant, G. L. Gill, Westech Systems, Inc., Prof. Oscar Stafsudd, UCLA	Ground	July 1982 To July 1983	To grow uniform silicon crystals through the use of microgravity conditions; to grow silicon crystals with dopant or alloy content in ranges that are impossible to grow at l-g. (These crystals are needed for a new infrared detection and imaging devices).	The slow relatively unfluctuating growth in space, with a tailored heat flux and and lack of gravity, allow for growth with much higher dopant and germanium concentrations.
114)	Aligned Magnetic Composites	Dr. D.J. Larson, Jr., Grumman Aerospace Corporation Bethpage, N. Y.	Ground	July 1978 To July 1983	To contribute to an understanding of the role of convection on plane front solidification of eutectic and peritectic composites, and on the relationship between morphology and magnetic properties; to assess the commercial potential for processing binary composites in low-g.	The low-g orbital environment will be utilized to study diffusion controlled solidification for experimental, convective/diffusive regimes (terrestrially). In addition, the relationship between solidification processing parameters, solidification microstructure, and magnetic properties will be studied.
115)	Rework of the SPAR Electromagnetic Levitator (EML) for Materials Experiment Assembly (MEA Accommodations	Dr. R. T. Frost General Electric Co.	Ground	October 1981 To Oct. 1982	To study the upgrade requirements and approaches needed for incorporation of an EML in the MEA carrier; to design and develop an engineering version of multisample specimen exchanger; to develop and test improvements in high temperature drop colorimetry techniques including new techniques for low gravity work; and, to carry out support tasks for the electromagnetic containerless processing Task Team.	This work provided progress in levitator technology.
116)	Thermocapillary Flows and Their Stability: Effects of Surface Layers and Contamination	Dr. S. H. Davis Northwestern University	Ground	June 1980 To June 1983	To theoretically analyze fluid mechanics and heat transfer of motions driven by surface-tension gradients; to gain an understanding of the convection accompanying the process of growing high-quality crystals in a low-g environment.	Work has been completed on several uncontaminated thin-film flows. These include the steady flow due to differential heating of a cavity and the instability characteristics of such flows. For small Prandtl numbers purely mechanical instabilities occur, while for large prandtl numbers thermal instabilities dominate. In all of the above analyses, the flows, the heat transfer, and the free surface shapes are simultaneously obtained.
117)	Semi-conductor Material Growth in Low-G Environment	R. K. Crouch A. L. Fripp Langley Research Center, In-Center	Ground	Feb. 1978	To utilize the microgravity environment of space to investigate the effect of convection on the homogeneity and perfection of compound semi-conductor crystals.	Three growth processes will be considered: (1) a vapor phase sublimation for seeded growth, (2) a modified Bridgmen configuration which encourages a single growth, and growth configuration.

CATEGORY 3 (CONTINUED)

118)	Aggregation of Red Cells	Dr. L. Dintenfass University of Sydney	Ground	1981	1) To determine whether the size of red cell aggregates, kinetics and the morphology of these aggregates are influenced by near-zero gravity; 2) To determine whether viscosity, especially at low shear rate, is afflicted by near-zero gravity (the latter preventing sedimentation of red cells); and 3) To determine whether the actual shape of red cells change and whether blood samples obtained from different donors react in the same manner to near-zero gravity.	It is possible that such data, obtained under near-zero gravity, when compared with equivalent laboratory data and subsequent procedures, will form the basis for diagnostic tests. The results of these tests with compounds at different concentrations may well prove to be distinctive for blood samples from patients suffering from different diseases.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY 4

	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
119)	New Polymers for Low-gravity Purification of Cells by Phase Partitioning	J. Milton Harris Univ. of Alabama Huntsville	Ground		To produce materials which will aid in space experiments to separate important cell types; and, to study the partitioning process in the absence of gravity, (i.e. in an equilibrium state).	Three new types of water-soluble polymers were synthesized. These are: (1) polyethylene glycols with attached crown ethers; (2) polyethylene glycols with attached cyclodextrins; and (3) dextans with attached long-chain hydrocarbons. The crown ethers and cyclodextrins are of interest because of their ability to selectively form complexes with, respectively, metal cations and hydrophobic anions. These nitrogen crowns upon protonation should also bind hydrophobic anions. Consequently, these materials present the possibility of specifically binding groups on the cell surface. The polymers with long-chain hydrocarbons attached are of interest because of the probable attraction of the hydrocarbon for lipophilic areas on the cell surface. Testing of the properties of these new materials has begun. An interesting spin-off has been the observation of catalytic activity for the crown polymers.
120)	Measurement of High Temperature Thermophysical Properties of Tungsten Liquid and Solid	Dr. D. W. Bonnell National Bureau of Standards			To evaluate experimental procedures used in the interaction between General Electric Advanced Application Laboratory (GE) and Rice University, to measure the high temperature enthalpy increments of liquid and solid tungsten.	The unique location of tungsten at the upper extreme of the metal and element melting point scale should provide a key part in any extrapolation/interpolation procedure.
121)	Gel Precursors as Glass and Ceramic Starting Materials for Space Processing Applications Research	Dr. R. L. Downs W. J. Miller KMS Fusion, Inc.	Ground		To determine experimental procedures used to produce gels starting materials for investigations of containerless processing in space. This processing is aimed at producing ultra high purity and/or amorphous materials such as glasses or ceramics, whose production under terrestrial conditions would be difficult.	Containerless processing requires the eliminations of melting crucibles and mechanical stirring to achieve compositional homogeneity.

122)	Acoustic Field Positioning for Containerless Processing	Dr. R.R. Whymark Intersonics Inc. Chicago, Ill. 60611	Skylab	1974	To describe a new type of acoustic position control system that can be adapted to existing space processing chambers with minimum modification to the chambers.	The system will operate satisfactorily at high and low temperatures and will be adaptable as an "add-on" feature to existing space experiments. The system has applications to containerless crystal growth, melting and related processes.
123)	Electromagnetic Containerless Melting and Solidification in the Weightless Environment	Dr. R.T. Frost General Electric, Philadelphia, Pa. 19101	Skylab	1974	To indicate general facility concepts capable of processing the widest possible range of important containerless processing experiments within reasonable technology constraints.	For early Space Lab applications, available power will be the principal limitation to the variety of materials which can be processed. For later manufacturing facilities, the system can be scaled up to commercial quantities through the addition of solar heating.
124)	Characterization of Semiconductor Materials	Dr. D.C. Gillies Universities Space Research Association Columbia, Md.	Ground	Oct. 1980 To Oct. 1981	To develop techniques for characterizing high-quality, solid solution, alloy type semiconductors for use as infrared detectors or as IR transparent substrates.	IR detectors can be grown by LPE or other techniques. Emphasis has been given to Hg.8Cd.2Te because of its importance as a detector material and because it is so difficult to grow on Earth.
125)	Hormone Purification by Isoelectric Focusing in space	Dr. Milan Bier Univ. of Arizona-Tucson	Ground	March 1978 To March 1982	To study the effects of gravity on the isoelectric focusing process; to define and produce a definite isoelectric focusing experiment, and, to refine future isoelectric focusing technology.	An inclusive list of gravitational hypothesis an gravitation effects will be generated. A study will be conducted to define a meaningful space experiment in isoelectric focusing. Conductivity sensors will be designed, constructed, and incorporated into the current hardware.
126)	Mathematical Models of Continuous Flow Electrophoresis	Dr. D.A. Saville, et.al. Princeton Univ.	Ground	August 1977 To Feb. 1983	To develop a comprehensive model of the actual 3-b flow temp. and electrical fields; to provide guidance in the design of electrophoresis chambers for specific tasks and means of interpreting test data on a given chamber.	Verification of the model is to provide the support necessary for the interpretation of microgravity operations. Recommendations are to be made for the design and operations of the ground experiments.
127)	Modeling Directional Solidification	Dr. W. R. Wilcox Clarkson College of Technology	Ground	May 1982 To May 1985	To develop tools used in explaining results of directional solidification in space. These tools will be both mathematical and experimental models.	Technologically important materials selected for solidification in space are high melting and opaque. Conditions during the growth of these materials, which are responsible for their microstructure, morphology, and inhomogeneities, are inferred with the aid of appropriate mathematical models and low melting transparent analogs.

CATEGORY 4 (CONTINUED)

128)	Dynamic Thermophysical Measurements in Space.	Dr. A. Cezairliyan National Bureau of Standards	Ground	April 1981 Cont. Task	To develop techniques for the dynamic (subsecond) measurement of selected thermophysical properties (such as heat capacity, heat of fusion, electrical resistivity) of solids and liquids at temperatures above 2000K in experiments to be performed near-zero-gravity environment.	Under the near-zero-gravity conditions, it might be possible to sustain a liquid column (specimen) for the duration of the brief experiment and thereby obtain, for the first time, accurate thermophysical properties data above the melting point of high melting substances.
129)	Biosynthesis/Separation Laboratory-Development of a Space Biosynthesis System and Biological Studies for Electrophoresis in Space	Dr. D.R. Morrison Mr. Bernard J. Mieszke	Ground	Jan. 1981 Cont. Task	1) To obtain data on the performance of cell culture vessel system elements and to define their biological oxidational process and, 2) determine the limits of ground-base technology using a preprototype reactor for studying enzymatic reactions and suspension cell cultures.	The laboratory has both monolayer and suspension cell culture capabilities. Current research includes procedures for the obtaining of cell cultures and the frazing and storage of cells. Procedures for growing cell cultures in suspension are being investigated.

APPENDIX B

SUMMARY OF SHUTTLE BORNE INVESTIGATIONS

This Appendix contains a summarization of the MPS experiments conducted on Space Shuttle flights STS-3 through STS-9. The information was derived from existing published literature.

The following compilation of Shuttle Borne experiments is extracted from ECOsystems International, Inc. Task III final report titled, "User Requirements for the Commercialization of Space", Contract NASW-3674. Task III collected MPS investigations conducted from initial ground studies through the startup of the Space Transportation System (STS) program.

Research underway on Task V has updated this data and expanded it to include investigations conducted through the STS 9 flight in December, 1983, presented here in Appendix B. The ultimate objective of this section of the formal report is to identify and capsulize available data on MPS investigation objectives and the Principal Investigator result analysis.

SUMMARY OF SHUTTLE BORNE INVESTIGATIONS
CATEGORY I

	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
1)	Monodisperse Latex Reactor (MLR)	Dr. John W. Vanderhoff Lehigh University	STS-3	March 1982	To study the feasibility of making large monodisperse (identical size) polystyrene latex microspheres (potentially up to 20 microns). To avoid the problems of coagulum formation, as well as creaming and sedimentation, as the particles grow in size and change density. wide. Some of the material produced will be used as seeds on following STS flights, (4,5, & 6).	Each of the four reactor chambers produced about 20 percent useable solids. One chamber produced spheres that were 0.2-0.3 microns wide to be used as a control to be compared with ground-based spheres. The others produced spheres about 3.5, 4.5, and 5.5 to 6.0 microns
2)	Monodisperse Latex Reactor (MLR)	Dr. John W. Vanderhoff Lehigh University	STS-4	June - July 1982	To study the feasibility of making large monodisperse (identical size) polystyrene Latex microspheres (potentially up to 20 microns). To avoid the problems of coagulum formation, as well as creaming and sedimentation as the particles grow in size and change density.	The chemical processing was not completed because of a hardware malfunction.
3)	Monodisperse Latex Reactor (MLR)	Dr. John W. Vanderhoff Lehigh University	STS-5	November 1982	To study the feasibility of making large monodisperse (identical size) polystyrene Latex microspheres (potentially up to 20 microns). To avoid the problems of coagulum formation, as well as creaming and sedimentation as the particles grow in size and change density.	14 hours of continuous Low G processing was completed. For results, see STS-7.
4)	Monodisperse Latex Reactor (MLR)	Dr. John W. Vanderhoff Lehigh University	STS-6	April 1983	To study the feasibility of making large monodisperse (identical size) polystyrene latex microspheres (potentially up to 20 microns). To avoid the problems of coagulum formation, as well as creaming and sedimentation as the particles grow in size and change density.	For results, see STS-7.

CATEGORY I (CONTINUED)

5)	Monodisperse Latex Reactor (MLR)	Dr. John W. Vanderhoff Lehigh University	STS-7	June 1983	To study the feasibility of making large monodisperse (identical size) polystyrene latex microspheres (potentially up to 20 microns). To avoid the problems of coagulum formation, as well as creaming and sedimentation as the particles grow in size and change density.	Spheres of 18 microns were grown producing end-products with five times the uniformity of 18-micron spheres grown on Earth.

SUMMARY OF SHUTTLE BORNE INVESTIGATIONS
CATEGORY 2

	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
6)	Vapor Growth of Alloy-type Semiconductor Crystals	Dr. Herbert Wiedemeier Rensselaer Polytechnic Inst. Dr. E.A. Irene IBM Dr. T.G. Wang RCA	STS-7	June 1983	To grow crystals of alloy semi-conductors and to provide data for a better understanding of the fluid dynamics of vapor transport systems in space.	
7)	Liquid Phase Miscibility Gap Materials	Dr. S.H. Gelles S.H. Gelles Associates Dr. A.J. Markworth Battelle Columbus Laboratory	STS-7	June 1983	To determine the manner in which the microstructural features of liquid-phase miscibility gap alloys develop. The results of such a defermination should make it possible to control the micro-structures and the resultant properties of these alloys.	One experiment was conducted to understand the droplet movement. The material used for this experiment was Aluminum and Indium, 90% Al by weight. The results showed the movement of droplets towards cooler end rather than the hotter end. The possible reason maybe: acceleration of the spacecraft, non-linear temperature gradient, compositional gradient, and interfacial energy computed theoretically different from what was actually induced. Three experiments were conducted to eliminate the "illuminating' free surface and gas bubbles. The material used in two experiments was aluminum and indium, and in those experiments the material used was Tellurium Thallium. The experiments did not work and massive seggregation of the 2nd phase was observed. The contributing factor may have been the Marangoni effect. The understanding of the above objective can be applied for development of: o Electrical Conductive materials o Magnetic materials o Super-conductive materials o Structural dispersion (multiproperty material) of strength within alloys

CATEGORY 2 (CONTINUED)

8)	Containerless Processing of Glass Forming Melts	Dr. Delbert E. Day University of Missouri - Rolla	STS-7	June 1983	To (a) obtain quantitative evidence for the suppression of heterogeneous nucleation/crystallization in containerless melts in micro-g, (b) develop the procedures for preparing precursor speciments that will yield bubble-free, high purity, chemically homogeneous melts in micro-g, (c) perform a comparative property analysis of glasses melted on earth and in micro-g and (d) assess the suitability of the single axis acoustic levitator/furnace apparatus for processing multicomponent, glass forming melts in micro-g.	The material used in this experiment was made up of calcium oxide, gallium oxide, and SiO_2. A partially melted sample was formed but the experiment was not completed due to the malfunction of the single axix acoustic levitator/furnace. The application is to prepare glass of high purity which could possess unique optical, electrical, and machanical properties.
9)	ES 301: Solidification of Immiscible Alloys	H. Ahlborn, University of Hamburg, FRG K. Lohberg, Technical University of Berlin, FRG	STS-9	November - December 1983	The immiscible metallic systems Al-In are to be studied as a follow-up to an earlier space experiment. Double Rack (MSDR)	100% of the planned objective of melting and subsequent solidification of the materials tested were accomplished utilizing the isothermal heating furnace in the Materials Science
10)	ES 302: Interaction Between an Advancing Solidification Front and Suspended Particles	D. Neuschutz and J. Potschke Krupp Research Centre, Essen, Germany	STS-9	November - December 1983	The matrix of the suspension of 1% aluminum oxide in copper produced by powder metallurgy is to be melted under microgravity. Particle spacing and size distribution will be determined to investigate the incorporation of the suspended particles in the crystal.	This experiment was not performed due to a failure in the isothermal heating facility.

CATEGORY 2 (CONTINUED)

11)	OES 303: Skin Technology	H. Sprenger, MAN Advanced Technology Munich, Germany	STS-9	November - December 1983	In the reduced-gravity environment, a very thin skin will be sufficient to retain the shape of a molten component. Directional solidification within a skin should lead to improved microstructures and physical properties for complicated geometries. A sample of a high-temperature eutectic alloy (Ni/Ni_3, Al-Mo) melting at 1310-1315^{o}C will be directionally solidified within a thin Al_2O_3 skin. The gradient heating device will be used.	This experiment was not performed due to a failure in the isothermal heating facility.
12)	ES 304/305: Vacuum Brazing	E. Siegfried W. Schonherr Bundesanstalt fur Materialpruefung Berlin, Germany R. Stickler & K. Frieler University of Vienna, Austria	STS-9	November - December 1983	Earth-bound investigations of brazing phenomena are restricted to narrow gaps, with interfering influences from the walls. Wider gaps can be filled by capillary-driven flow. The FSLP experiment will consist of an assembly of thin-walled tubes forming different concentric gaps to be brazed.	100% of the planned objectives were accomplished utilizing the isothermal heating furnace in the MSDR.
13)	ES 306: Emulsions and Dispersion Alloys	H. Ahlborn, University of Hamburg, FRG	STS-9	November - December 1983	Immiscible Metallic Systems Zn-Pb-Bi are to be studied.	100% of the planned objectives were accomplished utilizing the isothermal heating furnace in the MSDR. A total of twentyeight samples of zinc-lead-bismuth alloys were processed. The structures were analysed metallographically with sections marked "hotter areas". 1) small Zn droplets, as the minority phase (mp), were arranged between the melt and crucible wall; 2) the larger droplets of mp materials were enriched near the "hotter areas"; 3) a fairly homogeneous distribution of very fine droplets were observed only in zinc alloys; zinc droplets in the matrixes were bigger and inhomogeneously distributed.

CATEGORY 2 (CONTINUED)

14)	ES 307: Reaction Kinetics in Glass Melts	G.H. Frischat, Technical University of Clausthal Germany, et al.	STS-9	November - December 1983	Mass transport on Earth is governed in melts by convection (gravity-driven) and diffusion. The nearly convection-free conditions of space will be used to determine diffusion profiles in glasses.	This experiment was not performed due to a failure in the isothermal heating facility. Experiment planned to be repeated.
15)	ES 309: Metallic Emulsions Al-Pb	P.D. Caton, W.G. Hopkins, Fulmer Research Institute Slough, UK	STS-9	November - December 1983	This experiment will improve knowledge of the processing of immiscible materials by investigating effects of cooling rate and alloy composition on particle size and distribution in an aluminum-lead system solidified under microgravity.	Approximately 25% of the planned objectives were accomplished. The objectives not accomplished were due to a failure in the isothermal heating facility.
16)	ES 311: Bubble-Reinforced Materials	P. Gondi, University of Bologna, Italy, et al.	STS-9	November - December 1983	The behavior of microbubbles and microbubble particles during melting and solidification of metals and two-phase alloys is to be examined.	100% of the planned objectives were accomplished utilizing the isothermal heating furnace in the MSDR. Coatings with non-wetting films at 0-g show good combining efficiency; they remain detached from the metal after solidification. By contrast, when produced in 1-g, they adhere. Coating with wetting films of different thicknesses is inefficient in many cases. Lateral movements appear to condition solidification fronts. In the liquid, 0-g eutectic structures are consistent with smaller solidification rates or larger effective diffusion coefficients. In 0-g liquid, correlative statistical distribution curves of bubbles, have been drawn.

17)	ES 312: Nucleation of Eutectic Alloys	Y. Malmejac, CENG, Grenoble Cedex, France, et al.	STS-9	November - December 1983	The purpose of this investigation is to analyze the first step of solidification nucleation of a crystal inside the liquid phase. The alloys chosen (Ag-Ge, Al-Si, Al-Ge, Au-Si) are to be studied because of their particular behavior in the liquid state and during solidification. The eutectics obtained with a metal show extensive clustering and those with a semiconductor show extensive clustering in the liquid just above the melting temperature. The existence of these clusters seems to have a strong influence on nucleation.	Approximately 33% of the planned objectives were accomplished. The objectives not accomplished were due to a failure in the isothermal heating furnace. Partial and preliminary results indicate that measurement technique was successful. Conclusions have not been drawn.
18)	ES 313: Solidification of Near-Monotectic Zn-Pb Alloys	H. Fischmeister, A. Kneissl, R. Pfefferkorn & W. Trimmel, Montan University Leoben, Austria	STS-9	November - December 1983	Study of the solidification behavior and the resulting structures of immiscible Zn-Pb alloys and their dependence on the content and size distribution of lead particles, and on experiment temperature and time.	100% of the planned objectives were accomplished utilizing the isothermal heating furnace in the MSDR. Production, at slow solidification, of homogeneous dispersions of lead in the zinc matrix, was confirmed. Average droplet size increased. Lead droplets influenced by Marangoni convection were negligible.
19)	ES 314: Dendritic Growth and Microsegregation	H. Fredriksson, Royal Institute of Technology Stockholm, Sweden	STS-9	November - December 1983	The influence of convection on the formation of dendrite structures will be studied in binary Al-Cu alloys with different copper contents. The formation of dendrite arms as a function of different convection conditions will be examined. The microsegregation picture will also be evaluated as a function of different conditions.	100% of the planned objectives were accomplished utilizing the isothermal heating furnace in the MSDR.

CATEGORY 2 (CONTINUED)

20)	ES 315: Melting and Solidification of Metallic Composites	A. Deruyettere & L, Froyen University of Leuven, Belgium	STS-9	November - December 1983	The aims are: (i) to gain information on the usefulness of the microgravity environment in the production of metallic composite materials by casting, and (ii) to increase knowledge of the behavior of solid particles dispersed in a liquid metal. The proposed experiments consist of the melting and solidification under microgravity of metallic composite materials (Al-Al_2, Al-SiC, Cu-Al_2O_3,Cu-Mo and Cu-W) prepared by a powder metallurgical technique.	Approximately 50% of the planned objectives were accomplished. The objectives not accomplished were due to a failure in the isothermal heating facility. Several different aluminum and copper composites were utilized. Resultant enhanced bonding characteristics were observed due to the microgravity environment. Coarse and fine dispersed particle samples were more homogeneous, increasing the uniformity of macro-Vickers hardness. Also excellent abrasive wear resistance of the powder, AL-SiC composite, remains. Explanation of 1-g reference and < 0-g samples partial rearrangements by interfacial energy considerations is now feasible.
21)	ES 316: Solidification of Aluminum-Zinc Vapor Emulsion Under Microgravity	C. Potard, P. Morgand, CENG, Grenoble, France	STS-9	November - December 1983	The main objective is to analyse the mechanisms of formation of a zinc-vapor emulsion in liquid aluminum-zinc alloys and of its incorporation by solidification in the solid phase.	100% of the planned objectives were accomplished in the low temperature gradient furnace in the MSDR. Vapor phase nucleation was partially realized by the destabilization of the interfacial liquid zone. Bubble population was present in large volume fractions of the sample.
22)	ES 317: Solidification of Eutectic Alloys	J.J. Favier, J. De Goer CENG, Grenoble, France, et al.	STS-9	November - December 1983	The reduced thermal convection under microgravity should modify heat and mass transfer leading to a more regular structure in eutectic alloys. Studies will be performed on Al-Ni, Al-Cu and Ag-Ge. Solidification will be performed with a gradient of 20°C/cm with a rate of 2 cm/h.	100% of the planned objectives were accomplished in the low temperature gradient furnace in the MSDR. Results agree with previous thermal modelling of transient stages. Reducing the g-level by 3 or 4 orders does not affect the laser beam diffraction of interparticule space-growth rate relationships.

CATEGORY 2 (CONTINUED)

23)	ES 318: Lead-Telluride Crystal Growth Under Microgravity Conditions	H. Rodot, CNRS, Meudon France, et al.	STS-9	November - December 1983	Earlier results of semiconductor crystal growth under microgravity conditions have generally shown better quality products. The experiment will elaborate in more detail the influence of the different factors (convection, crucible, seed) on lead-telluride crystals.	100% of the planned objectives were accomplished in the low temperature gradient furnace in the MSDR. External surfaces of the crystals, one seeded, two unseeded, show specific effects of microgravity. Different conclusions on capabilities and limits of growth are inferred.
24)	ES 319: Unidirectional Solidification of Eutectics (InSb-NiSb)	G. Muller, University of Erlangen, FRG	STS-9	November - December 1983	During unidirectional solidification of a Te-doped InSb-NiSb eutectic, the NiSb needles are expected to grow perpendicular to the liquid/solid phase boundary. Both the length and direction of the NiSb needles and the distribution of the Te dopant are influenced by gravity. Processing under reduced gravity is therefore expected to result in a more uniform needle-growth and homogeneous dopant distribution.	100% of the planned objectives were accomplished in the low temperature gradient furnace in the MSDR. Proved a distinct influence of earth gravity on eutectic structures. Space grown eutectics have a refined structure explained by pure diffusive transport in the melt at the liquid solid interface.
25)	ES 320: Thermodiffusion in Liquid Alloys	Y. Malmejac & J.P. Praizez CENG, Grenoble, France	STS-9	November - December 1983	The thermodiffusion coefficients in different tin alloys will be measured in the absence of gravity. Tin will be used as a solvant. Thermodiffusion of different radioactive solutes will be studied. Thermodiffusion in single and polyphase crystalline growth is important for interface stability as well as the constituant distribution in the liquid and solid alloy.	100% of the planned objectives were accomplished in the low temperature gradient furnace in the MSDR. Relative concentrations varied from 0.7 to 1.4, cold end to hot end. Accuracy was better than 1%, and reproducibility is excellent. A value for heat of transport (- 5083 J/mole) can be deduced from those results.

CATEGORY 2 (CONTINUED)

26)	ES 321: Floating-Zone Growth of Silicon	E. Eyer & R. Nitsche, University of Freiburg, Germany	STS-9	November - December 1983	Silicon growth (1450°C) under microgravity should produce crystals with considerably fewer micro-inhomogeneities than Earth-grown materials. Ideally, the crystal should be free of striations, since temperature and concentration fluctuations due to gravity-driven convection are eliminated. Any remaining inhomogeneities should be due only to Marangoni convection. The experiment will allow us to distinguish between the (on Earth always combined) influences of buoyancy and Marangoni convection on the formation of microinhomogeneities. The use of radiant heat for zone melting also eliminates any turbulence effects (e.g. eddy currents) that an RF field may have on the melt.	100% of the planned objectives for experiment B were accomplished in the mirror heating facility in the MSDR. This experiment produced the first floating zone silicon crystal grown in space. Experiment A was not performed due to failure in the MHF.
27)	ES 322: Growth of Cadmium Telluride (CdTe) by the Traveling Heater Method (THM)	R. Dian, R. Schoenholz & R. Nitsche, University of Freiburg, Germany	STS-9	November - December 1983	The growth of CdTe under microgravity, under purely diffusive mass-transport conditions, should produce crystals with considerably fewer micro- inhomogeneities than Earth- grown materials. To insure monocrystallinity, a seed crystal, which will initially be partially dissolved, will be employed. The material will be evaluated by selective etching, infrared microscopy, X-ray topography and measurements of conductivity y-ray response and trap spectroscopy.	100% of the planned objectives were accomplished in the mirror heating facility in the MSDR. Experiment was halted prematurely due to difficulties with the cooling water supply of the furnace. Reasonable evaluation and characterization of the material were not feasible. However, it was shown that the THM of crystal growth, if sufficient growth time is allowed, is possible.

CATEGORY 2 (CONTINUED)

28)	ES 323: Growth of Ga-Sb Semi-Conductor Crystals	K.W. Benz, University of Stuttgart, Germany Erlangen-Nurnberg, FRG, et al.	STS-9	November - December 1983	The goal is to investigate the possibility of defined formulations in the solution, zone which should lead to more perfect and -- in terms of dopant distribution -- more homogeneous crystals. During the flight, about 5 mm of GaSb single crystals should be grown at an approx. 500°C solution temperature.	100% of the planned objectives were accomplished in the mirror heating facility in the MSDR. Advanced seed/solution interface can be achieved, in the Te-doped crystal exhibiting a more homogeneous distribution of dopants.
29)	ES 324A: Crystallization of an Si-DROP	H. Kolker, Wacher-Chemie Munich, Germany	STS-9	November - December 1983	A Silicon-drop, attached to a Silicon rod will be directionally solidified. Furnace temperature oscillations will be avoided and furnace cleanliness preserved.	100% of experiment A's planned objectives were accomplished in the mirror heating facility in the MSDR. Strong variations of growth rate are tentatively explained due to carbon contamination from the furnace. Clearly, there are temperature fluctuations in the melt other than from rotation in a nonsymmetrical heater.
30)	ES 324B: Crystallization	H. Kolker, Munich, Germany	STS-9	November - 1983	Marangoni convection (sur-convective disturbances will be present, so that its influence can be studied in terms of the inhomogeneities and striations in the crystals grown.	Experiment B was not performed due

CATEGORY 2 (CONTINUED)

31)	ES 325: Unidirectional Solidification of Cast Iron	T. Luyendijk, DELFT University of Technology, The Netherlands, et al.	STS-9	November - December 1983	Unidirectional solidification of pure Fe-C eutectic is to be studied with small quantities of sulphur and phosphorus as impurities. Measurement of sulphur concentrations along the length of the solidified specimen yields information on sulphur transport during solidification. From the segregation profile of sulphur in liquid ahead of the interface, it is possible to calculate the diffusion coefficient (ratio of solubility of sulphur in the solid to the liquid). This has not been possible so far on Earth due to the presence of convection.	100% of the planned objectives were accomplished utilizing the isothermal heating furnace in the MSDR Convection occurred even under microgravity conditions. Transients in the sulfur concentration at changing solidification rate proved a narrow diffusive boundary layer at the solid-liquid interface. In rapid cooling, the concentration showed oscillatory behavior. During eutectic growth, graphite flakes did not align more pronouncedly than at 1-g. The average lamellar distance between graphite flakes appeared smaller. The cast-iron rod and ceramic coating were studied.
32)	ES 326: Oscillation of Semi-free Liquid Spheres in Space	H. Rodot, Equip TCC, CNRS, Meudon, France, et al.	STS-9	November - December 1983	The effects of vibrations on liquid spheres in contact with a solid surface, simulating crystal growth from a levitated liquid, will be studied. In addition, the damping effect of a dashpot on liquid oscillations and positioning will be studied.	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Resonance frequency values (F_R) versus the ratio support diameter/liquid sphere diameter were determined. F_R decreases when sphere diameter increases. Amplitude value decreases when sphere diameter increases. Damping time increases when sphere diameter increases. Obtained results gave insight into sensitiveness to vibrations of liquids in levitation.
33)	ES 327: Kinetics of the Spreading of Liquids on Solids	J.M. Haynes, School of Chemistry, University of Bristol, UK	STS-9	November - December 1983	The major phenomena of spreading of liquids on solid surfaces are to be studied. These are of fundamental interest for physico-chemical hydrodynamics and many technological processes.	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Analysis is not yet complete, observations made include: orbiting maneuvering produced a very marked disturbance of the floating zone. Some evidence of electrostatic disturbance of the fluid.

CATEGORY 2 (CONTINUED)

34)	ES 328: Free Convection in Low Gravity	L.G. Napolitano & R. Monti, Institute of Aerodynamics University of Naples, Italy	STS-9	November - December 1983	In addition to studying the flow and temperature fields due to surface tension-driven action induced by one or more disturbances (temperature gradient, electric field, disc rotation), the experiment will also examine the regimes of surface-driven flows (e.g. Stokes, Navier-Stokes, boundary layer).	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Showed the largest ever attained floating zone, two orders of magnitude higher than earlier obtained on earth. The estimation of maximum velocity on the interface, will validate the theoreitical predictions of the Marangoni regime. This velocity is substantially smaller than other obtainable flow regimes
35)	ES 329: Capillary Forces in a Low-Gravity Environment	J.F. Padday, Kodak Research Laboratory, Harrow, UK	STS-9	November - December 1983	The main goal is to identify and measure the strength of long-range intermolecular forces between solids and liquids in molecular contact.	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Equilibrium shapes were reached very quickly, and the formation of the zone and its breakage were studied, revealing "inertial wetting". Preliminary results suggest that the disjoining pressure of the wetting film will be given by the capillary pressure measurements.
36)	ES 330: Coupled Motion of Liquid-Solid Systems in Near Zero Gravity	J.P.B. Vreeburg, National Aerospace Laboratory (NLR) Amersterdam, The Netherlands	STS-9	November - December 1983	As part of a wider program to investigate liquid-solid momentum-transfer mechanics for spacecraft attitude-control purposes, liquid motions in partially filled containers are to be studied. The motions generated by vibrating or rotating the containers are strongly affected by capillary forces from the free surface.	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Note that strictly speaking, this is not an MPS test in the accepted U.S. terminology. It is an experiment whose aim is to improve attitude orientation systems for spacecraft.
37)	ES 331: Floating-Zone Stability in Zero Gravity	I. Da Riva, I. Martinez ETSI Aeronauticos, Madrid, Spain	STS-9	November - December 1983	Stability limits can be examined by studying the fluid bridge between two equal discs, subjected to different mechanical perturbations (stretching, vibrating, rotation, etc.). This experiment has relevance for the floating-zone techniques used for crystal growth from the melt.	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Major difficulties in controlling interface positioning arose in flight. The liquid resisted its anchoring at the intended limits.

CATEGORY 2 (CONTINUED)

38)	ES 332: Organic Crystal Growth	Dr. K.F. Nielsen, Technical University of Denmark, Denmark	STS-9	November - December 1983	To study organic crystal growth in near-zero gravity and the effect of weightlessness on the crystals.	Approximately 50% the planned objectives were accomplished.
39)	ES 333: Growth of Manganese Carbonate	Prof. A. Authier, Universite' Pierre et Marie Curie, France	STS-9	November - December 1983	To study the growth of manganese carbonate in near-zero gravity and the effect of weightlessness on the manganese carbonate.	Approximately 100% of the planned objectives were accomplished.
40)	ES 334: Crystal Growth of Proteins	Dr. W. Littke, Christina John, Chemisches Laboratorium Der Universitat, Freidburg, FRG	STS-9	November - December 1983	To study crystal growth of proteins in near-zero gravity and the effects of weightlessness on the crystals.	Approximately 100% of the planned objectives were accomplished. Attempts to produce single crystals were successful. Crystals formed by "salting out" from solution kept free of convection were 27 and 1000 times larger in volume.
41)	ES 335: Self-Diffusion and Inter-Diffusion in Liquid Metals	Dr. K.H. Kraatx, Technische, Technische Universitat, Berlin, FRG, et al.	STS-9	November - December 1983	To study self-diffusion and inter-diffusion in liquid metals exposed to near-zero gravity and the effect of weightlessness on the liquid metals.	Approximately 100% of the planned objectives were accomplished. Comparison of tracer distribution should show the influence of Marangoni convection. The accurate determination of the temperature dependence of the diffusion coefficient is difficult due to data losses, i.e. during critical heat-up and cooling.
42)	ES 338: Crystal Growth of Mercury Iodide HgI_2 by Physical Vapor Transport	Dr. C. Belouet, Laboratories d'Electronique et de Physique Appliquee, France	STS-9	November - December 1983	To study crystal growth of mercury iodide by physical vapor transport in near-zero gravity and the effect of weightlessness on the mercury iodide crystals.	Approximately 100% of the planned objectives were accomplished.
43)	ES 339: Interfacial Instability and Capillary Hysteresis	J.M. Haynes, School of Chemistry University of Bristol, UK	STS-9	November - December 1983	The capillary behavior of fluids in porous media is dominated by hysteresis phenomena originating from instabilities in the fluid's interfacial configuration. ES 339 will examine both interfacial instability effects and capillary hysteresis.	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Results not yet reported.

CATEGORY 2 (CONTINUED)

44)	ES 340: Adhesion of Metals in Ultra High Vacuum Chamber	R. Rossitto, G. Ghersini, Milano, Italy	STS-9	November - December 1983	To study adhesion of metals in an ultra high vacuum chamber within a near-zero gravity environment.	Approximately 100% of the planned objectives were accomplished A small metallic sphere impacted against a metallic target; restitution coefficients, contact times, and time behavior of contact forces were measured as functions of incoming sphere velocity.

SUMMARY OF SHUTTLE BORNE INVESTIGATIONS
CATEGORY 4

45)	Electrophoresis Equipment Verification Test (EEVT)	NASA/JSC Dr. Dennis Morrison (JSC) Dr. Robert Snyder Snyder (MSFC Dr. Paul Todd Pennsylvania State University	STS-3	March 1982	To verify the operational suitability of the equipment and to repeat the MA-011 experiment under conditions which are optimum for the viability of human kidney cells and most favorable for the best possible electrophoretic separation of those few (about 5%) cells which produce urokinase or human granulocyte conditioning factor (HGCF) and Erythropoietin.	This test hardware was previously flown on the Apollo-Soyuz Test Project in 1975, however, malfunctions occurred that resulted in unsatisfactory cell separation on several experimental runs and less than optimum results in otherwise successful runs. The STS-3 test runs were successfully completed, however, test samples were destroyed by accidental thawing after return to ground facilities.
46)	Continuous Flow Electrophoresis System (CFES)	Dr. Charlie Walker McDonnell Douglas and Ortho Pharmaceuticals Division of Johnson and Johnson	STS-4	June - July 1982	This is an initial engineering test of the electrophoresis system hardware and will process six McDonnell Douglas protein samples. teins. A separation of 500 times the quantity possible on earth was achieved in space.	This experiment tests the McDonnell Douglas CFES. Two samples were tested, a mixture of egg and rat albumen and a cell culture fluid containing pro-
47)	Continuous Flow Electrophoresis System (CFES)	McDonnell Douglas and Ortho Pharmaceutical Division of Johnson and Johnson	STS-6	April 1983	(1) analyze the fluid flow and particle motions during continuous flow electrophoresis by experimentation and computation, (2) characterize and optimize electrophoretic separators and their operational parameters, and (3) separate biological cells using apparatus that has been characterized or modified to perform in a predictable manner and according to procedures that have been developed to yield improved separation.	This experiment continued the program of investigation and demonstration of the CFES process.
48)	Continuous Flow Electropheresis System (CFES)	NASA/MSFC Dr. Robert Snyder	STS-7	June 1983	(1) analyze the fluid flow and particle motions during continuous flow electrophoresis by experimentation and computation, (2) characterize and optimize electrophoretic separators and their operational parameters, and (3) separate biological cells using apparatus that has been characterized or modified to perform in a predictable manner and according to procedures that have been developed to yield improved separation.	This experiment continued the investigation begun in STS-3.

49)	Continuous Flow Electrophoresis System (CFES)	McDonnell Douglas and Ortho Pharmaceutical Division of Johnson and Johnson	STS-8	August - September 1983	(1) analyze the fluid flow and particle motions during continuous flow electrophoresis by experimentation and computation, (2) characterize and optimize electrophoretic separators and their operational parameters, and (3) separate biological cells using apparatus that has been characterized or modified to perform in a predictable manner and according to procedures that have been developed to yield improved separation.	Part of the experiments are being conducted for University researchers who are studying cell implantation for diabetes treatment. The test cells survived the space trip and preliminary indications are that the test samples yielded separation rates at the level MDAC and university researchers projected.

ABBREVIATIONS

ASTP	Apollo, Skylab, Apollo-Soyouz Test Project
CFES	The Continuous Flow Electrophoresis System
DFVLR	German Aerospace Research Administration
EAC	Experiment Apparatus Container
ELV	Expendable Launch Vehicle
ESA	European Space Agency
GHF	Gradient Heating Facilities
GSTDN	Ground Space Tracking and Data Network
IEF	Isoelectric Focusing
IFE	Interface Energies
IHF	Isothermal Heating Facilities
LDEF	Long Duration Exposure Facility
MEA	Materials Experiment Assembly
MHF	Mirrored Heating Facilities
MLR	Monodisperse Latex Reactor
MP	Minority Phase
MPS	Materials Processing in Space
MSDR	Materials Science Double Rack
MSFC	Marshall Space Flight Center
PI	Principal Investigator
SEP	Support Electronics Package
SLDPF	Spacelab Data Processing Facility
SPAR	Space Processing Applications Rocket
STS	Space Transportation System
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
THM	Travelling Heater Method
TM's	Technical Memorandum